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Organic Materials as Soil Amendments in Reclamation: A Review of the Literature

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Reclamation Research
Technical Advisory Committee

Alberta's Reclamation Research Program

Regulating surface disturbances in Alberta is the responsibility of the Conservation and Reclamatio Council. The Council Chairman is from Alberta Environmental Protection. The Council oversees a reclamation research program, established in 1978, to identify the most efficient methods for achieving acceptable reclamation in the province. Funding for the research program is provided by Alberta's Heritage Savings Trust Fund, Land Reclamation Program.

To assist with the development and administration of the research program, the Council appointed the inter-departmental Reclamation Research Technical Advisory Committee (RRTAC). Committee members represent the Alberta Departments of Agriculture, Food and Rural Development, Energy, and Environmental Protection, and the Alberta Research Council. The Committee updates research priorities, reviews research proposals, organizes workshops, and otherwise acts as the coordinating body for reclamation research in Alberta.

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Organic Materials as Soil Amendments in Reclamation: A Review of the Literature

by

Land Resources Network Ltd.

Prepared for

ALBERTA CONSERVATION AND RECLAMATION COUNCIL
(Reclamation Research Technical Advisory Committee)

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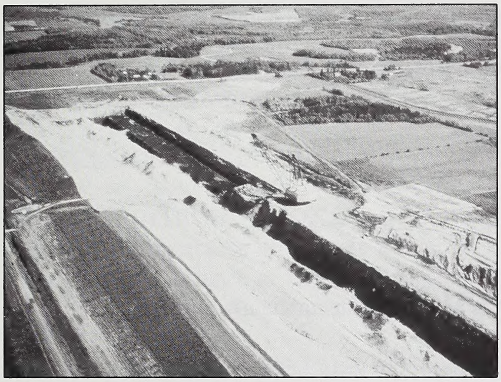

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DISCLAIMER

This report is intended to provide government and industry staff with up-to-date technical information to assist in the preparation and review of Conservation and Reclamation Approvals, and development of guidelines and operating procedures. This report is also available to the public so that interested individuals similarly have access to the most current information on land reclamation topics.

The opinions, findings, conclusions, and recommendations expressed in this report are those of the authors and do not necessarily reflect the views of government or industry. Mention of trade names or commercial products does not constitute endorsement, or recommendation for use, by government or industry.

REVIEWS

This report was reviewed by members of RRTAC.

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ABSTRACT

A review of pertinent literature was conducted to examine the effect of various organic materials when used as amendments to disturbed soil. The review was designed to be a reference document for government and industry staff involved in soil conservation and management of disturbed land. A literature base was established through extensive computer database and library searches and a survey of Alberta companies and government services was conducted to obtain information focusing on the use of organic amendments occurring in Alberta. Little of the literature dealt with the use of organic amendments specifically for land reclamation conditions similar to those found in Alberta.

Organic amendments reviewed included animal manures, crop residues, peat, wood waste, sewage sludge, municipal yard waste, humates, vermicomposts and spent mushroom compost. The effect of these organic amendments on soil chemistry, soil physics and soil biology was examined. Organic amendment application, costs, longevity of effects, and use in reclamation were also examined. Benefits and drawbacks for each of the amendments was discussed.

Adding organic amendments to soil quickly raises the level of soil organic matter, often resulting in improved biological, chemical and physical properties of the soil. Benefits of a single application of an amendment are not permanent. However, improved soil conditions provide a more favourable environment for plant establishment, critical for the buildup and maintenance of adequate soil organic matter contents. Growing plants provide a continual supply of organic matter inputs to soil.

Organic amendments do not take the place of normal topsoil salvage, storage and replacement. An organic amendment may be required when topsoil degradation has occurred or on an old disturbance where no topsoil was salvaged. Type of organic amendment used depends on the purpose of the amendment, cost and availability, and location and future use of the reclamation site.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the Reclamation Research Technical Advisory Committee (RRTAC) of the Alberta Land Conservation and Reclamation Council who managed the project. Funding for the project was provided through the Alberta Heritage Savings Trust Fund, Land Reclamation Program.

This review was a joint effort by several contributors. Writers included Karen Cannon, Nancy Finlayson and Dr. P. Michael Rutherford. Dr. Rutherford, Research Associate, Department of Soil Science, University of Alberta, also reviewed the material during the writing stage of this publication. Dr. W.B. McGill, Professor, Department of Soil Science, University of Alberta, provided an expert review. The literature search was carried out by Margaret Harris and Marilyn Bertsch. Margaret Harris also edited the final document. Vivien Pelletier helped in the preparation of tables and assembly of this document.

Special thanks are extended to those who provided information on availability and use of organic amendments in Alberta. The authors also wish to acknowledge comments and suggestions supplied by RRTAC committee members.

CONVERSIONS

Both SI and non-SI Units were encountered in the many papers read for this literature review. For consistency, non-Si Units were converted to SI Units and the SI conversions were reported first, followed in brackets by the non-SI Units. It should be noted that 1 Mg is equivalent to 1 tonne (1 t), 1 000 kg, 1.1 tons or 2 200 pounds. Also, 1 Mg/ha is the same as 0.45 tons/acre and 1 ton/acre is the same as 2.24 Mg/ha.

1. INTRODUCTION

Land Resources Network Ltd. was commissioned by the Reclamation Research Technical Advisory Committee (RRTAC), to compile a review of the literature on organic amendments to soil. The review was designed to be a reference document for government and industry staff involved in soil conservation and management of disturbed land.

The body of literature on the subject is immense. The use of animal manures and crop residues as amendments to agricultural soils, for example, has been studied for decades. Using composted municipal wastes and sewage sludge as soil amendments is a more recent innovation, and is the result of potential environmental problems arising from the disposal of such materials. Consequently municipal waste and sludge have received attention in the last 10 to 15 years. However, the use of other amendments such as wood wastes, peat, humates, and a number of other organic substances is much less common, and the body of pertinent information available is relatively small.

Very little of the literature deals with use of organic amendments specifically for the reclamation of disturbed lands. Even less reported on the use of organic amendments for land reclamation in conditions similar to those in Alberta. Consequently, information on some topics is incomplete, and its relevance to the Alberta situation unproven.

1.1 IMPORTANCE OF ORGANIC MATTER

Organic matter in the soil influences biological, chemical and physical soil properties. Although the organic matter content of topsoil is usually less than 10%, it accounts for or regulates much of the fertility status of the soil. A large proportion of the cation exchange capacity of a soil resides in its organic component, which also serves as a reservoir for plant nutrients in general, and the major reserve of nitrogen and sulphur. Other elements like phosphorus also occur in the soil in organic forms.

Soil organic matter along with soil biota and roots are responsible to a large extent for soil aggregation, tilth, and soil water characteristics. Soil water holding capacity, infiltration, permeability, and even surface crusting are improved with the addition of organic matter to the soil. Aggregate stability is critical to good soil tilth. A well aggregated soil not only encourages moisture infiltration, but also provides good drainage and aeration, conditions important to seed germination and plant growth. Because soil particles are physically bound together with organic substances, a soil high in organic matter tends to be less erodible.

Soil organic matter is critical to the reclamation of disturbed sites, whether the disturbance is a mine, pipeline or highway right-of-way, gravel pit, or petroleum lease. Restoring the productivity of a soil lacking organic matter is very difficult. Commercial fertilizers can supply required plant nutrients to an infertile site, but without organic matter the ability of the soil to retain and supply nutrients is diminished. If nutrients are not cycling through organic matter addition and decomposition, it will be very difficult for a site to support self-sustaining vegetation. Ripping can break up soil horizons compacted by heavy equipment at reclamation sites. However, without soil organic matter, the result can be a hard, blocky material with reduced capacity for water infiltration and retention.

In nature, soil organic matter increases from essentially zero in raw parent geologic materials to equilibrium levels during the process of soil development. Most soils in Canada are approximately 10 000 years old because they started forming from the geologic materials laid down from the last ice age. The main source of organic matter in soil is from the input of plant roots and litter from the grasses, trees and/or understory which have grown on the soils. The nature of soil organic matter differs from the original plant materials because most of it has been processed by the soil biological community and has also undergone various chemical reactions resulting in humified organic materials.

Soil organic matter contents in soils are determined by the rate of organic matter additions and the rates of organic matter losses. All soil organic matter is transient and eventually decomposes so organic matter additions are necessary to prevent net losses. In nature, organic matter contents are usually rather constant over time because the rate of plant residue addition to the soil in the form of roots and litter equals the loss through decomposition. Humans have great influence on soil organic matter contents by increasing or decreasing the rate of organic matter addition and rate of organic matter losses from soils.

1.2 IMPORTANCE OF ORGANIC AMENDMENTS

The goal of organic amendment additions to disturbed soils is to quickly raise the content of soil organic matter at the site so that the improved biological, chemical and physical properties of the soil result in a more favourable environment for the establishment of plants. The establishment of plants is critical for the maintenance of adequate soil organic matter contents in almost all soil systems because growing plants provide an ongoing supply of organic matter inputs to soils. The effect of organic matter additions, preferably through root and litter residues, is required to maintain adequate soil organic matter contents in the long-term.

Loss of some organic matter during land surface disturbance is common. Even with careful planning and construction some topsoil will be lost or diluted when the material is handled, whether through mixing with underlying subsoil, erosion, improper storage, or poor replacement. When replacement of topsoil becomes necessary, use of topsoil from an undisturbed land source is undesirable because a second disturbance, with potential loss of soil quality and productivity, is created. Stockpiled topsoil or areas with accumulated topsoil are more acceptable replacement sources. Organic amendments aimed at restoring soil organic matter content and its nutrient cycling function offer an alternative.

Organic amendments will be useful on old reclamation sites constructed before requirements for topsoil salvage, on sites where topsoil has been lost through carelessness or accident, and on sites with adverse chemical and physical conditions which make the improvement of soil capability, or the establishment of a self-sustaining vegetation cover difficult. Amendments can be useful on some properly reclaimed sites with no substantial losses of organic matter, to improve the fertility status and nutrient cycling role of soil organic matter quickly. An organic amendment may also be considered to improve adverse soil physical conditions due to soil compaction, pulverization, or mixing under wet conditions, regardless of the organic matter content of the soil. Organic amendments should not however, be considered as an alternative to proper soil conservation and implementation.

A variety of organic materials are available in Alberta for use as soil amendments including animal manures, crop residues, peat, woodwaste, sewage sludge, municipal yard wastes, humates and a number of composts. Although all these amendments are organic additions, their decomposition rates vary greatly, and their diverse chemical and physical properties have a variety of effects on the soil. Many are waste products of other industries, so that their availability in Alberta may be restricted to economical hauling distances from the industry itself. For example, animal manures are generated by the feedlot industry in large quantities in southern Alberta. Wood wastes are more likely to be available in central and northern Alberta, where forest industries are centred. Sewage sludge is most available near cities. Green manures are grown on the reclamation site itself.

1.3 ORGANIC AMENDMENTS AND SUSTAINABILITY

The main role of organic amendments in reclaiming disturbed sites is to assist in reconstructing a stable and self-sustaining soil system, under normal management practices, with a similar productive capability existing before disturbance. The purpose for applying organic amendments is not only to increase soil organic matter content to pre-disturbance levels for a given period of time, but more importantly, to assist in improving the quality of the soil-plant system cycles to levels equivalent in the undisturbed land system. The amendment is a critical step in the restoration of the soil-plant system and natural cycles of the soil.

A healthy soil can be defined as a living and breathing system because of the masses of organisms living in and depending on it; ranging from microscopic bacteria, fungi, and algae, to much larger nematodes, springtails and earthworms. Each organism has a role in decomposition of dead plant and animal tissues and making nutrients available to growing plants. When the soil at a site is disturbed, during construction, a number of disruptions can occur: vegetative cover is removed, topsoil is removed and often stored, and subsoil disturbed. Normal biological cycling of organic materials and plant nutrients from organic matter in the soil, into vegetative growth, and back into the soil again, is disrupted. Even after a disturbed site is reclaimed, cultivated and annually cropped, disruptions to soil organisms can adversely affect both physical and chemical properties of the soil.

Appropriate organic amendments on a reclaimed site can be considered a step to restoring the original soil-plant system. Organic amendments may stimulate increases in populations of soil organisms. Some amendments such as animal manures, also add a healthy and active microbial population to disturbed soils which may have very low populations. This can serve to "kick-start" nutrient cycling systems in soils which have been largely inactive during disturbance or storage. Once cycles are initiated, the soil-plant system can begin to cycle organic materials and nutrients, and ultimately produce and build up its own soil organic matter.

2. ORGANIC MATTER IN SOIL

2.1 INTRODUCTION

Soil organic matter is the fraction of the soil that contains biologically derived carbon, including plant and animal residues, soil organisms, microbial metabolites, and humified constituents less than 2 mm in size (Paul and Clark 1989). Living plant roots are excluded, but soil microorganisms are included. The various components of soil organic matter are in varying stages of decomposition. Humified constituents usually make up the bulk of the soil organic matter in most well drained soils (Stevenson 1982a). Sometimes soil organic matter is referred to as humus, but humus more correctly refers to the relatively stable dark colored fraction of the soil organic matter that remains after the bulk of the plant and animal residues has under gone microbial decay.

The chemical nature and physical properties of humus makes it resistant to further biological oxidation in the short term, but poor soil management practices may result in loss of even well-humified residues in the long term. Even the most resistant fractions of soil organic matter are undergoing constant decay and replenishment. Thus, for a constant amount of organic matter to be maintained in the soil, organic material must be continually added, either by plant growth or through human intervention.

2.2 COMPOSITION OF SOIL ORGANIC MATTER

Soil scientists have described soil organic matter in two ways: (1) using a chemical approach in which the chemical nature of the organic matter is described; and, (2) a kinetic approach in which differences in turnover rates between various organic matter fractions are stressed.

2.2.1 Chemical Approach

The traditional chemical approach divides soil organic matter into two major categories: nonhumified substances, and humified remains of plant and animal residues (Stevenson 1986). These two categories are not easily separable during chemical determinations.

Nonhumified soil organic matter consists of carbohydrates, proteins, lipids and microbiologically produced biochemicals. These compounds usually make up about one third of soil organic matter, depending on the amount and types of amendments added to soil (Stevenson 1986). Between 5% to 25% of soil organic matter consists of carbohydrates. Plants contain large amounts of carbohydrates in the form of cellulose, hemicellulose, starch and various amounts of sugars and amino sugars. Many of these carbohydrates are readily transformed through microbial metabolization and consequently microbially produced polysaccharides may dominate in soil. Such polysaccharides are important in the stabilization of soil aggregates (Oades 1984). Lipids consist of a diverse group of compounds consisting of fatty acids, fats, waxes and resins. Usually, in agricultural soils, between 1% and 6% of soil organic matter is made up of lipids; peats and acid forest soils may have higher levels (Stevenson 1986). Although proteins may enter soil as plant and animal remains, most proteins found in soil are produced by microorganisms.

Humified material is the dominant chemical component of soil organic matter, and usually accounts for about two-thirds of total soil organic matter. Humic substances, also called humates, are categorized according to their solubility in various caustic alkalis and acids. Humic acid for example, is soluble in alkali, but not in acid. Fulvic acid is soluble in both alkali and acid. Humin is insoluble in alkali. See Stevenson (1986) for a detailed chemical description of fulvic acids, humic acids and humin in soils. Some researchers believe that the harsh extraction procedure used to fractionate humic substances may alter the original material such that the material is not representative of what exists in soil (Juma and McGill 1986a,b). Newer methods such as NMR spectroscopy have provided evidence that humic substances may be less aromatic in nature than originally thought (Paul and Clark 1989).

Soil organic nitrogen has been chemically fractionated through hydrolysis using hot mineral acids followed by fractionation to determine the various forms of nitrogen (Stevenson 1982b). Only one-third to one-half of the organic nitrogen in most soils can be accounted for in compounds such as amino acids and amino sugars. This method may be so harsh, however, that it alters the original material, making interpretation difficult.

2.2.2 Kinetic Approach

This approach is based on differences in turnover rates between various fractions of soil organic matter (Juma and McGill 1986a,b). The organic matter is separated into classes based on biological availability, regardless of chemical makeup. Although the microbial biomass makes up only a small proportion of the total mass of soil organic matter, it is considered in the kinetic approach to be a very important component because its activity controls the availability of several important nutrients (N, S, and P) to plants. The microbial biomass and its recently deposited by-products, which comprise approximately 5% to 15% of total soil organic nitrogen, are termed the 'active' organic fraction (Paul and Juma 1981). The bulk of soil organic matter is 'stabilized' or 'old', however. Despite the small amount of active organic matter in soil, it has a relatively rapid turnover rate compared to the stabilized and old organic matter fractions and therefore it is important for supplying nitrogen to plants through mineralization (Jansson 1958). Paul and Juma (1981) determined that the microbial biomass, active organic matter, stabilized organic matter and old organic matter made up 4%, 10%, 36% and 50%, respectively, of the total soil organic matter in a Saskatchewan Chernozemic soil. The half-lives under moist, warm conditions were estimated to be 7 weeks for the microbial biomass, 27 weeks for the active organic matter, 165 weeks for the stabilized organic matter and greter than 600 years for the old organic matter. Models which describe soil organic matter and nutrient cycling dynamics in prairie soils are developed in McGill et al. (1981a,b), Parton et al. (1988), Paul and Juma (1981) and Voroney et al. (1981).

2.2.3 Humus Forms in Forest Soils

Leaf litter accumulation in forest soil has been classified into three different "humus forms" (Russell 1973). The term "humus forms" which relates to degree of mixing and organo-mineral complexing, should not be confused with the word "humus", which denotes soil organic colloids. The "mull humus form" is characteristic of forest soils formed under deciduous trees in base rich parent material. In these conditions abundant soil organism activity mixes and distributes the organic material within the surface mineral horizon. As a result, there is no abrupt change in organic matter between the organic litter layers and the surface mineral horizon. These soils tend to be among the most productive forest soils. The "mor humus form" is characteristic of soils that form under coniferous forest under cool, wet conditions in base-poor parent materials. Acidic conditions, high tannin content, and high carbon to nitrogen ratio of the leaf litter contributes to a much lower biological activity than in the mull situation. As a result, there is little mixing of the organic litter layers with the mineral soil, causing an abrupt change in organic matter content between the litter and the surface mineral horizon. The "moder humus form" is characteristic of soils formed under coniferous forests of warmer temperatures than in the mor situation, and on base-rich parent materials. Under these conditions there is intermediate biological activity, resulting in intermediate mixing of the litter layers and the surface mineral horizon.

2.3 IMPORTANCE OF SOIL ORGANIC MATTER

Stevenson (1982a) outlined the general properties of humus and its associated effects in soil are summarized in Table 1.

2.3.1 Plant Nutrients and Nutrient Ratios

Soil organic matter is a major reservoir of N, S, and P. Over 90% of soil nitrogen, up to 90% of soil sulphur, and between 10% and 50% of soil phosphorus exist in organic forms in surface soil horizons. These nutrients have to be converted to inorganic forms in a process of mineralization before they can be utilized by plants. Usually about 1% to 3% of soil organic matter is mineralized in a growing season. Mineralization occurs during the decay process and is carried out by soil microbes and associated soil fauna. It therefore is influenced by factors which affect biological activity, such as pH, temperature, moisture, and aeration.

Also important are the C:N, C:S, and C:P ratios of the organic material. In most soils the proportion of C:N:P:S of soil humus is about 140:10:1.3:1.3. If the ratio of C to N, P or S is very high in an organic amendment, the microbes decomposing it may remove plant-available inorganic forms of N, P and S from the soil solution to meet their needs for growth and incorporate the nutrients into their cell structure. This process, called immobilization, is the opposite of mineralization because inorganic plant available nutrients are converted into unavailable organic forms. Both mineralization and immobilization normally occur simultaneously in soils. When immobilization predominates, net immobilization is said to occur. When mineralization predominates, net mineralization occurs. As a general rule, when plant and animal residues are added to soil net mineralization occurs if C:N ratios of the decomposing part of the residues are less than 20:1, if C:P ratios are less than 200:1 and C:S ratios are less than 200:1. In contrast, net immobilization occurs if residue C:N ratios are greater than 30:1, C:P ratios are greater than 300:1 and C:S ratios are greater than 300:1. Some organic residues with high C:N, high C:P or high C:S ratios do not always case net immobilization, however, net mineralization may occur if much of the carbon is in highly resistant molecules such as lignin, because not all the carbon is readily available for microbial decay, resulting in lower "effective" C:N, C:P or C:S ratios.

Organic matter reacts with metal ions in soils. Whereas single charged cations are held mainly by simple cation exchange, some important multi-charged cations such as heavy metals

Table 1. General properties of humus and associated effects in the soil.[a]

Property	Remarks	Effect on Soil
Colour	The typical dark colour of many soils is caused by organic matter	May facilitate warming
Water retention	Organic matter can hold up to 20 times its weight in water	Helps prevent drying and shrinking. May significantly improve the moisture-retaining properties of sandy soils
Combination with clay minerals	Cements soil particles into structural units called aggregates	Permits exchange of gases Stabilizes structure Increases permeability
Chelation	Forms stable complexes with Cu^{2+}, Mn^{2+}, Zn^{2+}, and other polyvalent cations	May enhance the availability of micronutrients to higher plants
Solubility in water	Insolubility of organic matter is due to its association with clay. Also, salts of divalent and trivalent cations with organic matter are insoluble. Isolated organic matter is partly soluble in water.	Little organic matter is lost by leaching
Buffer action	Organic matter exhibits buffering in slightly acid, neutral, and alkaline ranges	Helps to maintain a uniform pH in the soil
Cation exchange	Total acidities of isolated fractions of humus range from 300 to 1400 meq/100g	May increase the cation exchange capacity (CEC) of the soil. From 20% to 70% of the CEC of many soils is due to organic matter.
Mineralization	Decomposition of organic matter yields CO_2, NH_4, NO_3, PO_4, and SO_4	A source of nutrient elements for plant growth
Combines with organic molecules	Affects bioactivity, persistence and biodegradability of pesticides	Modifies application rate of pesticides for effective control

[a] Source: Adapted from original table in Stevenson (1982a).

may form complex chelation linkages with organic matter (Stevenson 1982a). Chelation reactions are very important in soils. When relatively small organic molecules such as fulvic acids chelate with metals they tend to keep the metal more soluble than when no chelates are present. The environmental effect may be positive or negative. If the metal is required for plant growth, the effect is beneficial; however, if the metal is toxic and present in high concentration due to pollution or unwanted loading then the effect is harmful. Conversely, if the metal combines with a large insoluble organic lignin such as humic acids or humin, a required plant nutrient may become immobile and thus will not reach the plant root. On the other hand, toxic heavy metal complexes reduce the mobility of the metal, thereby producing a beneficial effect by reducing its mobility in the environment.

2.3.2 Cation Exchange Capacity (CEC)

Cation exchange is the process whereby positively charged plant nutrients (cations) held on negatively charged soil surfaces are made available to plant roots by entering the soil solution through exchanging for some other cation (often H^+ from the solution). Soil humus contains many negatively charged chemical groups that are involved in cation exchange. Humus colloids are often responsible for 20% to 70% of the CEC of soils. Increases in soil humus content will therefore increase the soils' ability to hold cationic plant nutrients such as ammonium, calcium, magnesium, potassium, cobalt, manganese, iron, copper and zinc. Another benefit of increased CEC is an increase in buffering capacity of the soil. Other factors being equal, soils with a greater CEC will be more resistant to changes in pH than soils with a lesser CEC.

Humified soil organic matter is colloidal (10^{-4} to 10^{-7} cm in diameter) and has a very large surface area per unit mass. As a result, it tends to be more reactive than larger nonhumified organic particles in soil. It is also highly charged per unit mass due to reactive hydroxyl, carboxylic or phenolic groups. The CEC of humus increases with pH. CEC typically ranges between 150 and 300 meq per 100 g soil (Bohn et al. 1979).

2.3.3 Biological Effects

Oxidation of soil organic matter to CO_2 provides soil organisms with a source of energy. High biological activity is usually positively correlated with nutrient turnover and favourable soil physical properties. The production of microbial residues and fungal hyphal growth bind individual soil particles into aggregates, thereby improving soil structure. Organic matter and microbial populations interact with soil fauna, which also impart desirable physical conditions to soil.

Soil organic matter has a number of other effects as well (Stevenson 1982a, b, 1986). Denitrifying organisms and free-living nitrogen fixing microorganisms require an energy source; therefore, denitrification and nitrogen fixation may be affected by available organic matter in the soil. Growth of soil microorganisms on added organic matter may result in production of microbial chelates. Chelates are organic chemicals that combine with nutrient cations, thereby increasing their solubility and potential availability to plants. Increased microbial activity may also provide some protection from plant pathogenic organisms. Lipids may have various effects on plant growth. Some compounds (e.g., aldehydes, ketones, phenolic acids, coumarins, glycosides and some aliphatic acids) are toxic to plants, while others (e.g., B vitamins) may enhance plant growth.

2.3.4 Effects on Physical Properties

Humus improves aeration, water-holding capacity, and water infiltration of soils. It increases aggregation, and improves soil tilth by creating a loose granular condition which is easy to till. Improved aggregation, infiltration, and greater water holding capacity result in less erosion because runoff is reduced and individual particles are less likely to be carried away by running water. Improved soil physical conditions result in better plant growth. Large improvements in yields are often observed when humus levels are increased in sandy or clayey soils. The dark colour of humus absorbs solar energy; therefore, large increases in soil organic matter may facilitate the warming of soils in spring.

2.4 ORGANIC-INORGANIC INTERACTIONS

Soil organic matter is closely associated with the inorganic component of the soil. Organic compounds are held on clay mineral surfaces or possibly within the interlayers of expanding clays (Stevenson 1982a). Thus fine-textured soils tend to have higher organic matter contents than coarse-textured soils. Nitrogen-containing compounds often complex with clays, thereby protecting compounds so that their availability to microbial degradation is reduced. Although net nitrogen mineralization is usually greater in soils with a high soil organic matter content, fine-textured soils may mineralize a lesser proportion of their total organic nitrogen in a given period of time than coarse-textured soils (Campbell and Souster 1982; Rutherford and Juma 1989a).

Tillage or other human activities may disturb the soil so that this "protected" organic matter may become more accessible to the biological community. Along with improved aeration, tillage induced reorganization of soil particles may increase the rate at which organic matter decays.

In addition, soil fauna are less successful at feeding on smaller organisms such as bacteria in fine-textured soils than in coarse-textured soils, thereby partially reducing fauna-induced nitrogen mineralization (Rutherford and Juma 1992).

2.5 SOIL ORGANIC MATTER CYCLE

Soil organic matter is most closely tied to the carbon cycle (Figure 1). Soil N, S and P cycles are also linked with soil organic matter but will not be discussed in detail here. Usually the greatest source of carbon input into soils is from plant residues. In grasslands, and cropped lands where above-ground material is removed, plant roots are often the most important carbon input into the soil. Dead roots are important, but living roots also deposit much organic material in the form of sloughed root hairs and mucilage compounds (Curl and Truelove 1986). Once carbon-containing compounds are added to soils they are metabolised by microorganisms that require carbon as an energy source and as a structural material for their cells. Some carbon is released to the atmosphere as carbon dioxide (CO_2) as the organisms utilize the organic compounds for energy, while the rest is incorporated into microbial cell tissue. Carbon that enters the soil microbial community fuels the decomposer food web. Some carbon that has been transformed by the decomposer food web is neither lost as CO_2 nor assimilated by organisms. Instead, it becomes stabilized in the soil as humified organic matter. This material is still decaying but at a reduced decomposition rate relative to freshly added organic materials. Over time, organic matter increases in soils until the rate of accumulation approximates the rate of loss via decomposition. At this point, the soil organic matter content is said to be in a steady state. Human activity can disrupt the natural steady-state condition of the soil however, resulting in a net change in the soil organic matter content.

2.5.1 Soil Biology

The soil community is characterized by a large number and wide diversity of organisms (Alexander 1977; Coleman et al. 1983; Richards 1974; Russell 1973). Most soil organisms obtain their energy and building blocks to construct body tissue from plant or animal tissues. The majority (saprophytes) feed on dead tissue; some feed on living microorganisms and smaller fauna. Bacteria and fungi make up the bulk of the soil community. However, the larger soil fauna are also important members of the decomposer food web because they reduce the particle size of plant residues, thereby speeding up microbial decomposition. Also, some fauna feed on bacteria and fungi and therefore regulate microbial activity and decomposition rates. Coleman et al. (1983)

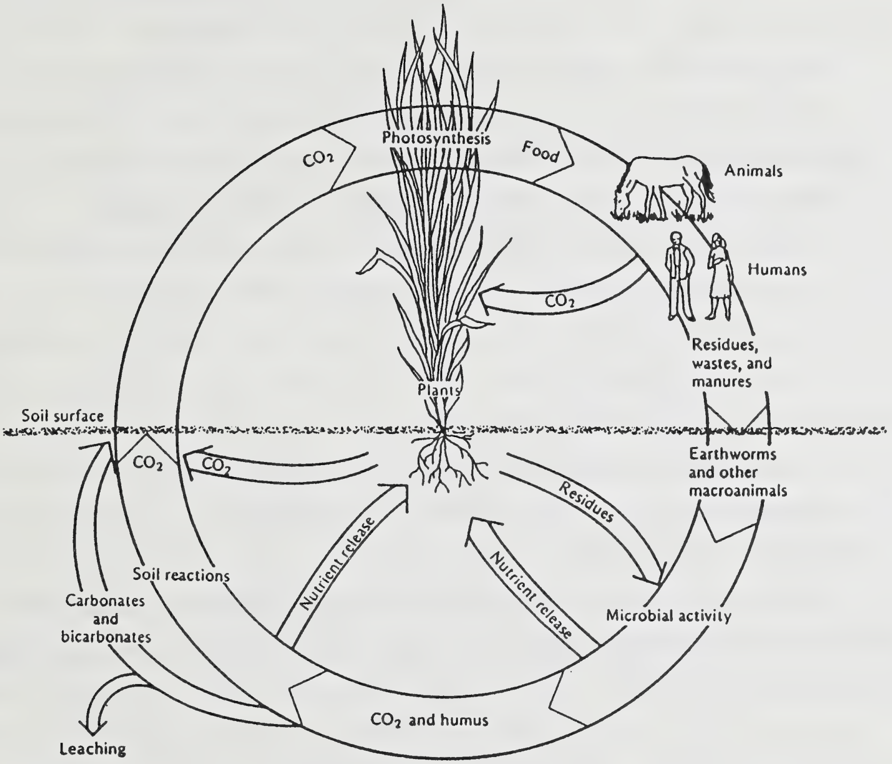

Figure 1. Transformations of carbon commonly known as the carbon cycle, the biocycle, or life cycle.[a]

[a] Source: After original figure in Brady (1990).

argue that vigorous soil faunal populations keep soil microbes in a more active state, thereby speeding up decomposition and mineralization of N, P, and S.

Most decomposers in soils are aerobic, that is they require oxygen for respiration. Anaerobic organisms that use other compounds instead of oxygen in their respiration processes, can decompose organic matter in saturated soils where oxygen is lacking, but the decomposition rate is much slower than aerobic decomposition. Anaerobic organisms play other important roles in the cycling of nutrients in the environment. However, not all of the nutrient transformations carried out by anaerobic organisms are desirable in arable soils. For example, anaerobic denitrifying bacteria convert nitrates to nitrogen gas, which is then lost from the soil to the atmosphere.

The number of soil organisms is greatest in the surface horizons where soil is rich in organic matter, chemical substrates, nutrients and oxygen. Microbial populations (soil bacteria and fungi) are generally higher near plant roots (rhizosphere) because plant roots are continuously releasing organic matter. Some rhizosphere microorganisms are plant parasites but most are saprophytes which use the released organic matter as a source of energy. Predatory soil fauna feed on saprophytic microorganisms, resulting in a complex food web in the vicinity of plant roots. Rhizosphere microorganisms influence plant growth. For example, nitrogen fixers and mycorrhizal fungi provide plant roots with nutrients and water. Other microorganisms produce compounds that inhibit pathogens from attacking plant roots. Still others produce organic compounds that promote plant growth or increase the efficiency of nutrient uptake. Because of the importance of soil microorganisms, Thurber Consultants Ltd. et al. (1990) suggested that topsoil stockpiles should be seeded and a vegetative cover be maintained.

The following is a brief description of soil organisms. Readers requiring further details can refer to Alexander (1977); Edwards et al. (1988); Paul and Clark (1989); Peterson and Luxton (1982) or Russell (1973).

2.5.1.1 Soil microorganisms. Soil microorganisms include microflora (bacteria, fungi, algae) and microfauna (protozoa). Bacteria and fungi constitute the greatest mass of the soil microbial community. Some bacteria and fungi are autochthonous; they are relatively slow growing organisms that methodically metabolise the more stable forms of organic matter in soil. They dominate when no readily decomposable organic material is available in soil. If fresh, readily available organic matter is added to soil, fast growing, opportunistic zymogenous bacteria and fungi rapidly increase in number. These organisms subsist on easily decomposable organic compounds, and are thought to lie dormant until fresh organic material is added to soil.

2.5.1.1.1 Bacteria. Bacteria are the most numerous organisms in soil. They often make up about one third of the microbial mass of prairie soils, the remaining two thirds being largely fungi. One gram of soil typically contains between 10 million and 1 billion bacteria. Bacteria are unicellular, and most are less than 1 micrometre long. They are a very diverse group being represented by approximately 200 genera. Bacteria are capable of using a broad range of substrates and of carrying out an extremely wide range of biochemical reactions in soils. The reproductive rate of zymogenous bacteria exceeds that of other soil organisms, thereby allowing them to utilize readily available substrates quickly. This is advantageous in the soil where substrates for energy are often the most limiting factor to biological activity.

Bacteria that obtain their energy from the oxidation of inorganic elements in soil are referred to as autotrophs. Although autotrophs are present in low numbers in soils they are important in the transformation of plant nutrients. Examples of autotrophs are nitrifiers, which oxidize ammonium to nitrate, and sulphur oxidizers which form sulphate from reduced forms of sulphur, such as sulphide or elemental sulphur.

2.5.1.1.2 Fungi. Fungi are unicellular or multicellular microorganisms that lack chlorophyll and often grow in a filamentous fashion. They are commonly known as moulds, mildews, rusts, smuts, yeasts, mushrooms and puffballs. Approximately 170 genera of fungi are represented in soil. Paul and Clark (1989) classified soil fungi into five broad groups; slime moulds, flagellate fungi, sugar fungi, higher fungi and the imperfect fungi. Fungi are at least as important as bacteria for the decomposition of organic residues in soil, and are especially important for the decomposition of resistant woody plant materials containing cellulose and lignin. Brown rot and possbily some xenobiotics are capable of decomposing cellulose but not lignin; white rots are capable of decomposing both cellulose and lignin. Because bacteria move in soil solution, their movement may be limited if the soil is dry or if pores are discontinuous. Fungi, on the other hand, are capable of extending their filamentous hyphae across dry pores to reach the substrate. Thus fungi are able to function at lower soil moisture contents than bacteria (Bamforth 1985; Griffin 1981). In contrast to bacteria which can only adsorb compounds contained within the soil solution in which they live, fungi are capable of mechanically penetrating the substrate without it being in solution. This action is pronounced in the organic layers of the forest floor, where fungal hyphae are essentially the only decomposers of the woody material in this relatively dry environment. Soil fungi generally are more tolerant of wide ranges in soil pH than are bacteria, which generally cannot tolerate low pH. Consequently, under acidic conditions, fungi play a relatively larger role in decomposition than bacteria.

2.5.1.1.3 Algae. True algae are unicellular and multicellular microorganisms that are capable of photosynthesis. Because photosynthesis requires light, these organisms are not as common as bacteria or fungi. True algae include green, brown, and red algae, and diatoms. Algae are important during the process of soil development. They can colonize barren or recently exposed sites and provide an initial source of soil organic matter and nitrogen. Colonization by algae reduces erosion and makes the parent material more hospitable to higher plants, which are the major source of soil organic matter during later stages of soil development.

Blue-green "algae" are actually photosynthetic bacteria that may exist in unicellular or filamentous forms. Also known as cyanobacteria, these organisms fix nitrogen from the atmosphere.

2.5.1.1.4 Protozoa. Free-living protozoa (unicellular animals) are very numerous in soils. They are the smallest of the soil fauna and range in size from slightly bigger than bacteria to almost macroscopic in size. The protozoa can be broadly classified into four main groups: small flagellates, naked amoebae, ciliates, and testacea. Some protozoa feed on dissolved organic matter, but many are predators of bacteria, yeasts, smaller protozoa, and other soil fauna. Small flagellates and amoebae are the most important predators of soil bacteria. Protozoa thus influence bacterial populations and nutrient cycling. Smaller bacterial populations of high metabolic activity are often associated with protozoan feeding. This has been shown to speed up nutrient cycling in soil. Most soil protozoa are very sensitive to desiccation and their mobility and activity becomes limited in dry soils.

2.5.1.1.5 Microbial biomass. Collectively, the soil microorganisms are called the soil microbial biomass. Microbial biomass carbon and microbial biomass nitrogen have been reported to average 533 ug carbon per gram soil and 64 ug nitrogen per gram soil, respectively, in a cultivated Black Chernozem in central Alberta (Dinwoodie and Juma 1988; Rutherford and Juma 1989a,b). A cultivated Gray Luvisol from central Alberta was found to average 242 ug/g soil and 38 ug/g soil, respectively of microbial biomass carbon and nitrogen (Dinwoodie and Juma 1988; Rutherford and Juma 1989a,b).

2.5.1.2 Soil metazoa. Soil metazoa (sometimes referred to as mesofauna and macrofauna), are multicellular animals, most of which are large enough to be seen by the naked eye. Nematodes or roundworms are the smallest (usually less than 0.05 mm wide and 2 mm long) and most numerous of the metazoa. Some nematodes are plant parasites but most are free-living and feed on microflora or smaller fauna (Peterson and Luxton 1982). Populations of nematodes affect the populations and activities of bacteria, fungi, protozoa and smaller nematodes, and as a result, they influence decomposition and nutrient cycling in a way similar to that described for protozoa feeding on bacteria.

Other soil metazoa include springtails, mites, earthworms, spiders, beetles, ants, woodlice, millipedes, centipedes, snails, slugs, potworms, and insect larvae. Their diets are varied and include detritus, fungi, and other fauna. Their activities generally result in more rapid decomposition and nutrient turnover. These organisms play an important role in the development of good soil structure and in the maintenance of a healthy active microbial community.

Soil fauna larger than nematodes have relatively long lives compared to the smaller fauna and the soil microorganism community. Larger fauna are also more easily killed by physical disruption of the soil. As a result, populations of the larger soil macrofauna may be reduced in arable soils that are subjected to conventional tillage. Reduced tillage results in a larger and more diverse decomposer food web. Grassland soils tend to have greater numbers and diversity of soil organisms than cultivated soils, due to the greater input of root carbon from grasses and less physical disruption of the soil.

Table 2 summarizes microbial biomass carbon and faunal population numbers (excluding earthworms) for cultivated soils in western Canada.

2.5.1.3 Earthworms. In many parts of the world, earthworms make up the bulk of the soil faunal biomass, sometimes approaching the mass of bacteria in soil (Brady 1990). Earthworms are not present in all prairie soils although they have been introduced in some areas. Soil scientists on the prairies have often found large numbers of earthworms in areas where worms were not thought to be present (S. Pawluk, Department of Soil Science, University of Alberta, personal communication 1992). However, data from the prairies are rare (Shaw 1984).

When present, earthworms affect the physical and chemical properties of the soil. For this reason they are considered to be the most important of the macrofauna. They influence the distribution, and nature of soil organic matter, and promote physical and chemical reactions between minerals and organic matter (Shaw and Pawluk 1986a,b).

There are many types of earthworms (Shaw 1984). Some live near the soil surface and do not make many burrows in the mineral soil horizons. They consume detritus, either in the litter layer or in the upper-most layers of the mineral soil. Other earthworms, such as the common garden earthworm (*Lumbricus terrestris*) make both shallow and deep burrows. These types of worms are considered the most important in terms of improving soil quality, because they feed on

Table 2. Microbial C and faunal populations of selected cultivated soils.[a]

Depth (cm)	Mean	Site description[b], crop and sampling dates	Reference
Microbial C (ug/g soil) by CFIM[c]			
0-7.5	260	Swift Current, Saskatchewan; L; 8-year wheat; Oct 1982	Biederbeck et al. (1984)
0-7.5	469	Indian Head, Saskatchewan; C; wheat; June 1982	Campbell et al. (1986)
0-15	310	Breton, Alberta; SiL; oats of 5-year cereal-forage rotation; July-Aug 1984	Fyles and McGill (1987)
0-5	166	Breton, Alberta; SiL; barley of 5-year rotation; May-Oct 1982	McGill et al. (1986)
0-10	242	Breton, Alberta; barley	Rutherford and Juma (1989a)
0-10	533	Ellerslie, Alberta; barley	Rutherford and Juma (1989a)
Protozoa (number per gram by MPN[d])			
0-10	19×10^5	Breton, Alberta; barley	Rutherford and Juma (1989a)
0-10	13×10^5	Ellerslie, Alberta; barley	Rutherford and Juma (1989a)
Nematodes (number per m^2)			
0-15	4.1×10^6	Breton, Alberta; SiL; oats of 5-year cereal-forage rotation; July-Aug 1984	Fyles and McGill (1987)
0-20	1.0×10^6	Breton, Alberta; barley	Rutherford and Juma (1989a)
0-20	5.1×10^6	Ellerslie, Alberta; barley	Rutherford and Juma (1989a)
Mites (numbers per m^2) by high-gradient heat extraction			
0-10	2.0×10^4	Breton, Alberta; barley	Rutherford and Juma (1989a)
0-10	4.3×10^4	Ellerslie, Alberta; barley	Rutherford and Juma (1989a)

[a] Source: Adapted from original table in Rutherford and Juma (1989a).

[b] C, clay; L, loam; Si, silty; S, sandy.

[c] CFIM, chloroform-fumigation incubation method.

[d] MPN, most probable number.

vegetation at or near the soil mineral surface and drag it into burrows for feeding. The burrows increase soil aeration and drainage which contribute to soil tilth. Redistribution of plant litter from the soil surface into the mineral horizons increases soil organic content in these layers and speeds up its transformation to humus. Undigested material passes through the gut and back out into the soil in earthworm casts, which can in turn be infested by other earthworms. Earthworm casts increase both the size and stability of soil aggregates. Organic debris in casts is subject to vigorous microbial attack due to the maceration and digestive "softening" of organic material which occurred in the gut. The amount of available carbon, nitrogen, phosphorus, and exchangeable bases is usually greater in casts than in the bulk soil. These earthworms are important in the formation of mull humus forms which are present in the upper layers of forest soils formed under deciduous forest vegetation.

Earthworms may consume massive amounts of soil as they burrow through the upper soil layer searching for food. Russell (1973) reported that earthworms in pasture consumed 89 tonnes of soil per hectare per year and produced 62 tonnes of casts per hectare per year. In arable soils the total soil consumed was much less, only 12 tonnes per hectare per year with a production of 7 tonnes of casts per hectare per year, because earthworms are killed by tillage, and don't have a short enough life cycle to come back quickly.

Earthworms prefer moist but well-aerated soils with pH above 4.5 (Russell 1973). Cold temperatures reduce earthworm activity and many will burrow deep in the soil to avoid unfavourable temperature or moisture conditions. The highest numbers occur in soils that receive organic additions because earthworms need organic matter as a source of food.

2.5.1.4 Soil enzymes. All biochemical reactions are catalyzed by enzymes which are proteins that speed up specific reaction rates. Enzymes are produced by all organisms and are fundamental to life. Extracelluar enzymes are found outside the living organism and are often entrapped in soil organic matter and inorganic colloids. These enzymes originate from microorganisms which either constantly release the enzyme or do so when a susceptible substrate or other initiator is present. Many extracelluar enzymes hydrolyse complex materials such as cellulose into simpler forms which can be taken up by microorganisms. Because soil enzymes are protein molecules they are an ideal food source for other microorganisms. Consequently, they only persist in soil if protected chemically or physically, or if they are continuously being produced by living cells. Examples of soil enzymes include urease (hydrolytic breakdown of urea), phosphatases (hydrolytic breakdown of various organic phosphates), sulphatases (hydrolytic breakdown of organic sulphate compounds) and dehydrogenases (involved in oxidation of organic matter). Tabatabai (1982) provides a good review of soil enzymes.

2.5.2 Description of Decomposition

Decomposition is a biological process. Therefore the rate is dependent on conditions that affect the activity of microorganisms. Ideal conditions for microbial activity are warm temperatures, moist conditions, and unlimited aeration. Maximum microbial activity is found between 25° and 35° C, at approximately 60% of the soils water-holding capacity (Jenkinson and Powlson 1976; Paul and Clark 1989). Soils with good tilth possess the ideal structural conditions necessary for an active microbial community. Neutral pH and adequate nutrients will also encourage a diverse, active biological community. Particle size of organic substrates is important as well. Small particles have a larger surface area to volume ratio and usually greater access to internal surfaces than do larger particles; consequently, microorganisms decompose smaller particles faster than larger ones.

Decomposition of organic matter requires the interaction of organisms and substrate; therefore, the architecture of the soil and substrate is important (McGill and Myers 1987). The location of substrates within organic residues and within the soil matrix affects the availability of the substrates to the biological community, and hence affects the rate of decomposition. Some constituents of plant residues are more physically available than others. Also, some plant residues within the soil mineral matrix may be contained in regions away from soil organisms, while others are readily available for attack. These physical factors will affect the overall decomposition rate and nutrient turnover.

Growing plants may also influence decomposition of soil organic matter. Dormaar (1990) suggested that growing roots usually conserve soil organic matter by exerting physical or biological effects on the soil. General conclusions in this regard are not warranted because the data are still contradictory (Dormaar 1991).

Decomposition has been described mathematically by Juma and McGill (1986a,b), McGill and Hoyt (1977), and Paul and Clark (1989). According to first order kinetics, the amount of decomposition is dependent on the concentration of the organic substrate in soil, but the proportions decomposing per unit time is constant. The more substrate present, the greater the amount of decomposition. Equations describing organic matter decomposition have practical value because they can be used to calculate the length of time required for decomposition to occur (the potential life of an amendment) and the amount of nitrogen required to prevent net nitrogen immobilization.

The equation which describes first order decompostion kinetics may be expressed mathematically several ways:

(change in A)/(change in time) = -ka (eqn. 1)

$At = Aoe^{-kt}$ (eqn. 2)

$\ln At - \ln Ao = -kt$ (eqn. 3)

where:
A is the concentration of the substrate (e.g. straw) in soil;
At is the concentration of substrate after time, t;
Ao is the original concentration of the substrate in the soil;
t is time; and
k is the decomposition rate constant for the substrate under specified conditions.

Details of first order kinetics are present in Appendix 1. As a practical example of decompostion consider the scenario where cereal straw is incorporated at an application rate of 2 tonnes (dry matter) per hectare into a fallow field soil in central Alberta.

Question 1. How much of the original straw would remain in the soil after one year?

According to van Veen and Paul (1981) the decomposition rate constant for wheat straw on the prairies is about 0.003 day^{-1} (note, a value of 0.008 day^{-1} is used if only the summer months are of interest; the lower 0.003 day^{-1} value takes into a account the fact that pratically no decomposition occurs when the soil is frozen). After a year the concentration of undecomposed straw in the soil would be:

$\ln At - \ln Ao = -kt$
$\ln At = \ln Ao - kt$
$\ln At = \ln (2 \text{ tonnes/ha}) - (0.008 \text{ day}^{-1} \text{ X } 365 \text{ days})$
$\ln At = 0.693 - 2.920 = -2.227$
$At = e^{-2.227}$
At = 0.11 tonnes original straw remaining per hectare

Therefore, 1.89 tonnes per hectare of straw decomposed over the year (2 - 0.11 = 1.89). Approximately 40% of the plant carbon that decomposed would have been converted into carbon dioxide and was lost into the atmosphere. Approximately 60% of the plant carbon that decomposed was converted into new soil organic matter, including microbial tissues and non-living soil organic matter. This newly formed soil organic matter will also decompose, but generally at a slower rate than the original plant material.

Question 2. How much mineral N would have to be present in the soil in order to prevent net N immobilization during the first year?

Plant dry matter contains about 44% carbon content (Brady 1990). The C to N ratio of straw is about 70 (Stevenson 1986). A C to N ratio of about 25 is required to prevent net N immobilization. The amount of plant C which decomposed in the year is 0.83 tonnes per hectare (44% of 1.89 tonnes per hectare). The amount of N present in the decomposed plant material is 0.012 tonnes per hectare (0.83/70). The total amount of N needed to prevent net N mineralization is 0.033 tonnes per hectare (0.83/25); therefore the amount of mineral N that must be supplied either by the soil or by fertilizer addition is 0.021 tonnes per hectare (0.033 - 0.012). A soil test for mineral N would be helpful to determine whether fertilizer N is required.

Data for calculating decompositon rates of various organic substrates in Alberta field soils are sparse. Most decomposition studies of various substrates in soils have been conducted in the laboratory under ideal conditions of moisture, temperature and aeration. Often the material is ground to reduce the substrate particle size. This further enhances the decompositon rates in the laboratory. Decomposition under these conditions may be 10 times faster than in prairie field soils during the summer (Van Veen and Paul 1981). These studies are still useful at a pratical level because they still allow relative comparisons to be made of different substrates. For example, Table 3 from Haider (1992) shows that under identical laboratory conditions the decomposition rate of cow manure is approximately the same as wheat straw, just slightly lower than fresh corn matter, but much faster than Douglas fir sawdust and peat moss.

Van Veen and Paul (1981) presented a mathematical model which described organic matter decomposition in the field. Figure 2 shows how decomposition rates in the field can be estimated from laboratory data (Van Veen and Paul 1981). This figure shows how reduction factors are used to reduce the ideal laboratory decompositon rate when temperature and/or moisture conditions are limiting.

2.5.3 Nature of Humus Formation

Most organic matter additions to agricultural and forest soils are from fresh or modified plant residues. Even manure contains a large component of partially digested plant residues. Typical green plant residues are mostly water (Figure 3), with only about 25% made up of dry matter. Within the dry matter, over half of the chemical compounds are carbohydrates, mostly

Table 3. Decomposition of various organic compounds and plant residues in Greenfield sandy loam topsoil.[ab]

	Decomposition After Weeks[c]				
Substrate	1	4	12	20	28
Glucose	73	82	89	90	90
Starch	48	69	81	84	86
Cellulose	27	52	77	79	84
Green matter (corn 28 days)	27	45	69	73	82
Lima bean straw	36	57	75	78	79
Wheat straw	20	33	59	61	64
Corn straw	18	31	60	63	65
Cow farmyard manure	18	33	43	48	50
Prune wood (sawdust)	12	25	33	40	45
Almond shells	12	24	37	39	41
Douglas fir (sawdust)	2	5	15	29	34
Peat moss	< 1	3	8	14	17
Soil humic acid	< 1	< 1	1	1	2

[a] Source: After original table in Haider (1992).

[b] Dry, powdered (1mm) material was mixed (1000 ppm) with soil and incubated at the -33 kPa water potential at 22°C in the laboratory under continuous aeration.

[c] Percentage of added carbon evolved as CO_2.

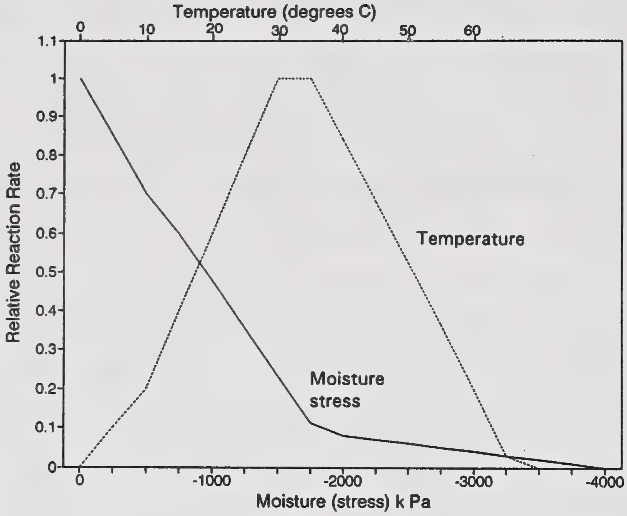

Figure 2. Relative reaction rates for organic matter decomposition at various stresses and temperatures (1 kPa = 0.01 bar).

Source: After original figure in Van Veen and Paul (1981).

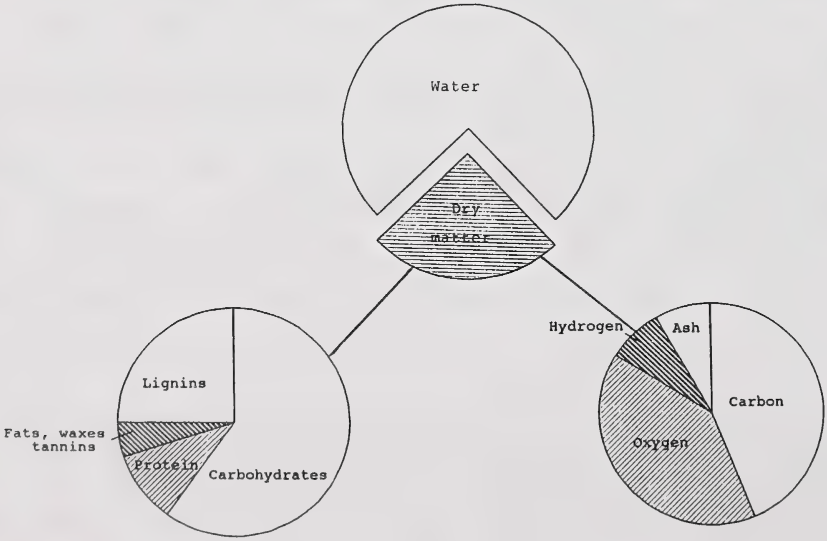

Figure 3. Composition of representative green plant materials added to soils.

Source: After original figure in Brady (1990).

cellulose and hemicellulose. From 10% to 30% of plant residues may be composed of lignins, which are very difficult to decompose. Older plants tend to have a larger proportion of lignin than younger ones, making the older plants more "woody".

When fresh plant material is added to soil the microorganisms metabolise it sequentially: first decomposing the simple sugars, starches, and simple proteins, followed by the crude proteins, cellulose and lipids in that order. Lignin has the slowest decomposition rate; therefore, over time the decomposing substrate becomes relatively enriched in lignin and other polyphenolic compounds. During metabolism by microorganisms some simple compounds arising during decomposition (amino acids, amino sugars, and polysaccharides containing amino sugars), are incorporated through side reactions into the humic polymers, and make up a large proportion of the nitrogen contained within the humic matter. These complex plant and microbially-derived compounds polymerize under oxidative reactions, resulting in the formation of large humic substances. According to Brady (1990), one year after the addition of organic residues, 60% to 80% of the original carbon has been given off as CO_2, the balance remains in the soil as soil organisms (3% to 8%), non-humic compounds (3% to 8%) and complex humic compounds (10% to 30%).

2.6 METHODS OF MEASURING SOIL ORGANIC MATTER

Nelson and Sommers (1982) state that no completely satisfactory method exists to determine the total organic matter content of soils. One procedure that is commonly used indirectly estimates the organic matter content by multiplying organic carbon content by the ratio of the organic matter to organic carbon commonly found in soils. Generally a ratio of 1.724 is used. Organic carbon can be determined by measuring the difference between total carbon and inorganic carbon, by measuring the total carbon after removal of inorganic carbon, or by determination of total C by dichromate oxidation, either with or without heat. Direct methods of determining total soil organic matter are to measure the loss in mass following destruction of organic compounds by hydrogen peroxide treatment or by combustion at high temperatures. Use of hydrogen peroxide is unsatisfactory for quantitative analysis because oxidation of organic matter is often not complete and varies among soils. Combustion is the more acceptable method if the soil is first treated with acids to remove water from soil minerals, and if a suitable correction factor is used to account for the slight losses in organic matter during the acid pretreatment. Readers should refer to Nelson and Sommers (1982) for details on methods of determining soil organic matter.

Page et al. (1982) describe methods of determining specific fractions within the soil organic matter. These include the classical method of extraction and fractionation of humi (Schnitzer 1982) and the method of organic nitrogen characterization (Stevenson 1982b). Stevenson (1982a) describes the procedures used to determine specific carbohydrates in soils.

The soil organism community is also part of soil organic matter. Several chapters in Page et al. (1982) are dedicated to methods for determining specific groups of organisms. Dindal (1990) is the first major work dedicated to the classification and enumeration of soil organisms.

Microbial biomass is commonly determined by the chloroform fumigation incubation method (Parkinson and Paul 1982) or the chloroform fumigation extraction method (Vance et al. 1987). The most common methods of determining the activity of the biological community measure the mineralization of carbon (the formation of carbon dioxide from soil respiration) or the net mineralization of nitrogen in laboratory incubation studies. Soils containing organic matter that is of high quality and readily available to the biological community will mineralize significant quantities of carbon and nitrogen in the laboratory. Various chemical extraction procedures have also been devised to predict the potential mineralizable nitrogen content of soils (Keeney 1982; Juma and McGill 1986a,b). Measurement of the soil enzyme dehydrogenase has also been used as a measurement of biological activity in soil (Tabatabai 1982).

2.7 FACTORS AFFECTING THE DISTRIBUTION OF SOIL ORGANIC MATTER

Canadian soils are relatively new because most have formed since the last glaciation. Soils form as the result of four basic processes: addition, loss, translocation, and transformation of matter. The factors that control these processes are parent material, climate, vegetation, topography and time. These factors determine the amount and nature of the soil organic matter and the type of soil which is formed.

In Alberta, the dominant soil types (orders) are Chernozemic, Solonetzic, Luvisolic and Organic (Agriculture Canada Expert Committee on Soil Survey 1987). The amount and nature of the organic matter differs between and within Soil Orders.

Most soils in the province have formed on mineral parent material and contain less than 30% organic matter. The amount, distribution, and type of soil organic matter differs greatly depending on whether the soil formed under predominantly grassland or forest vegetation. Chernozemic and Solonetzic soils formed under conditions where grass roots were the major source of carbon input. In contrast, Luvisolic soils formed under mainly forest vegetation where leaf litter and woody debris were the major sources of carbon input. Leaf litter is deposited on the surface of the soil instead of within the mineral layers as is the case for grass roots. The result is that Chernozemic soils have deep A horizons (topsoil) which may be high in organic matter content. In noncultivated Luvisolic soils on the other hand, much of the leaf litter is decomposed on the mineral soil surface, resulting in the formation of organic horizons (also called litter layers) above the mineral soil surface. The mineral horizons of a Luvisolic soil contain less organic matter than do those of a Chernozemic soil and decrease more rapidly with depth. Figure 4 shows the distribution of organic matter in a typical Black Chernozemic soil and a Gray Luvisolic soil. When Luvisolic soils are cleared of trees and converted to agricultural production, the leafy organic horizons are lost, and productivity declines after a few crops unless chemical fertilizers or organic amendments are used.

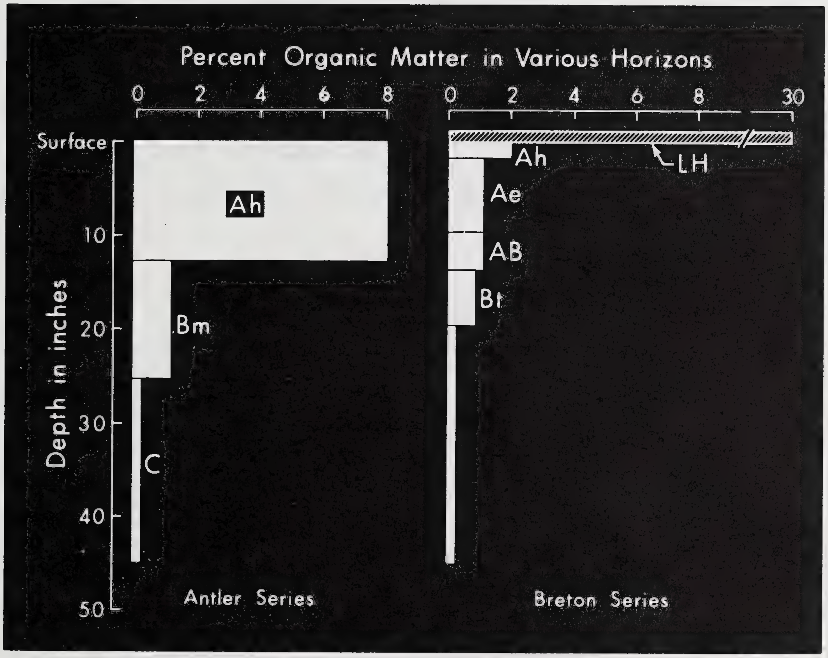

Figure 4. Percent organic matter in various horizons in a Black Chernozemic soil (left) and a Luvisolic soil (right).[a]

[a] Source: After original figure in Bentley et al. (1971).

Organic matter content also varies with the landscape. Generally, organic matter is greatest at lower slope positions. Lower positions are wetter and usually have more vegetative growth, resulting in greater input of organic matter. Organic matter content and A horizon depths in cultivated soils also tend to be greater in lower slope positions due to erosion of organic-rich topsoil from slopes to depressions.

Other factors being constant, fine-textured soils generally have greater soil organic matter content than coarse-textured soils. There are several reasons for this. First, fine-textured soils tend to have greater moisture reserves and hence plant growth than coarse-textured soils, and therefore greater input of organic matter. Second, the rate of decomposition of added residues is often slower in fine-textured soils. Fine-textured soils may "protect" organic residues better from the decomposing organisms, or may reduce the efficiency of the decomposer community. Third, once formed, humic substances may form organo-mineral complexes with clay colloids, thereby reducing their availability to further biological activity.

Organic soils occupy large regions of the north-eastern part of the province. They formed under saturated conditions where the rate of addition of organic matter was slow. Cold temperatures and reduced oxygen slowed activities of soil fauna and microorganisms that were responsible for decomposition or conversion of plant materials into more resistant humus. As a result, these soils have formed from parent material composed mainly of plant residues. Organic C content exceeds 17% (<30% organic matter).

2.8 ORGANIC CONTENTS IN SOILS OF ALBERTA

To date the most comprehensive documentations of levels of soil organic matter in Alberta are McGill (1989) and Reinl (1984). Figure 5 shows the average concentration of organic C in cultivated and native A horizons for the soil zones of Alberta (Reinl 1984). Of the cultivated (Ap) horizons examined, soils of the Black Zone had the highest mean organic carbon concentration, followed by soils of the Dark Gray Zone, Peace River area, Dark Brown Soil Zone, Gray Luvisol area, and Brown Soil Zones in descending order. Mean organic carbon concentrations of noncultivated soils in the same areas were quite different. Gray Luvisols and soils of the Peace River area had the highest concentrations of organic carbon before cultivation, but ranked 5 and 3 once cultivated. This is because much of the organic carbon in these soils in their uncultivated state was relatively nondecomposed litter (LFH). Once incorporated into the soil, this material decomposes into more humified material, and concentrations of organic carbon in the soil are dramatically reduced.

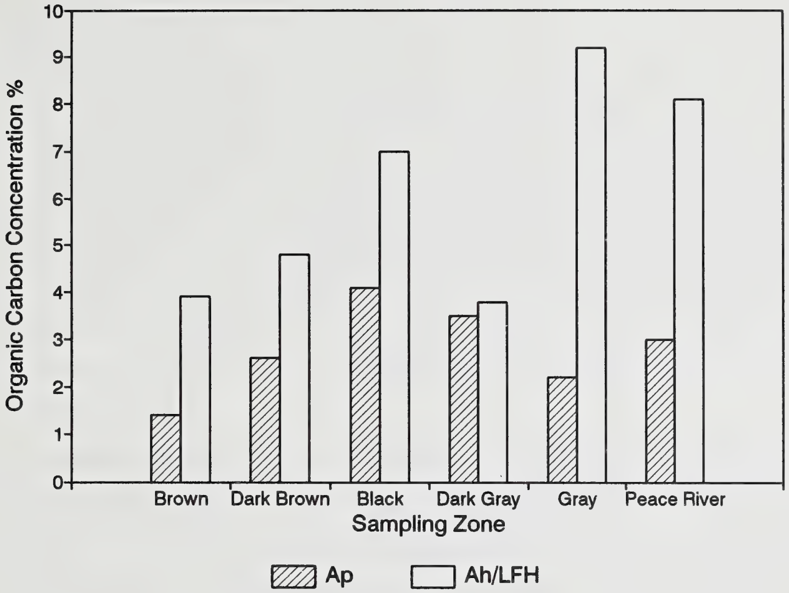

Figure 5. Average concentration of organic carbon in cultivated and native A and/or LFH horizons of soils in Alberta.[a]

[a] Source: Adapted from original table in (Reinl 1984).

2.9 IMPACT OF HUMAN ACTIVITY ON SOIL ORGANIC MATTER

Total soil organic matter contents are the result of two dynamic processes; additions and losses. Humans can have a profound effect on these processes and therefore on levels of soil organic matter. The problem of declining soil organic matter in Canadian prairie soils has been documented by Campbell et al. (1976), McGill et al. (1981a) and Reinl (1984). McGill et al. (1981a) estimated that the average loss of organic matter from A horizons in Alberta due to human activity was 42%. Reinl (1984), in an extensive study of organic matter in cultivated and noncultivated soils throughout Alberta, found that the concentration of organic carbon in cultivated A horizons had decreased by 52% (Brown), 42% (Dark Brown), 40% (Black), 13% (Dark Gray), 75% (Gray Luvisolic) and 64% (Peace River) sampling zones. Some of the decrease in concentration, particularly in the Gray Luvisolic and Peace River areas was due to soil redistribution; that is, soil layers with lower organic matter content were mixed during cultivation with upper layers containing higher organic matter content. Surface layers appear to have lost substantial organic matter, although total organic carbon to plough depth may not be substantially different. Because reductions in soil organic matter concentrations can occur through mixing with no changes in total amount or mass of organic matter, the change in concentration often overestimates the change in mass of organic matter.

It is important to stress that all soil organic matter is transient. Old soil organic matter decomposes like freshly organic materials, but it does so at a slower rate. The overall half-life of soil organic matter in a prairie wheat-fallow soil is about 30 years (Paul and Clark 1989). Some organic matter fractions have smaller half-lives and some other fractions have longer half-lives than this overall average, but all are undergoing decay and will eventually have to be replaced by new C. Consequently, organic matter additions must be maintained in order to prevent a net loss of organic matter in soil.

Organic matter is lost mainly through oxidation to CO_2 by soil organisms when they use the material for energy. Human activity often speeds up the decomposition process by improving its accessibility to microorganisms. Soil tillage mixes the soil, which both aerates it and exposes new organic matter to microorganisms. Organic matter which previously was "protected" within a soil aggregate or within a certain part of the soil profile may be moved to a location more accessible to bacteria or fungi. Frequent passes of tillage equipment over the soil reduces soil aggregate sizes. Smaller aggregates have a greater surface-to-volume ratio, which increases the availability of substrates to biological attack. Reduced tillage practices have been shown to increase the amount of organic matter in soils.

Soil organic matter is also lost by erosion. Poor soil management often increases the rate of wind or water erosion. Concentrations of organic matter are greatest near the soil surface and therefore any topsoil erosion probably involves the loss of significant amounts of organic matter as well.

Humans can also control rates of addition of organic matter. This can be accomplished by controlling plants grown in the soil as well as by directly adding residues or amendments. A decrease in the amount of plant material added to the soil is one of the main reasons for the decrease in soil organic matter concentrations on the prairies. The natural grassland supplied the soil with large amounts of organic materials for millenia. When these soils were brought into cultivation organic inputs were decreased, because annual cereals do not have the extensive root systems of grasses, and because the grain was removed and the straw either removed or burned. Summerfallowing, which aims to store soil moisture for the following growing season, reduces levels of soil organic matter in two ways. Firstly, soil organic matter decomposition is increased due to increased tillage and moisture conditions (microbes require moisture for activity). Second, organic inputs are eliminated for a whole growing season.

Ideal management practices for improving amounts of soil organic matter should normally include grasses and legumes in rotation, if the soil is to be used for annual crops although continual annual crops have been shown to increase soil %C. Total soil organic carbon and nitrogen are often more closely related to the amount of plant residue nitrogen rather than residue carbon (Campbell et al. 1991a). Liming, fertilization and irrigation also help maintain higher organic matter levels by maximizing plant biomass production. The effects of crop rotation and cultural practices on soil organic matter is sometimes not as marked in soils already containing high levels of organic matter (Campbell et al. 1991b).

Another way organic inputs can be increased is through the direct addition of materials containing organic matter. These materials are varied and are the primary focus of this report.

2.10 POSSIBLE PROBLEMS WITH ORGANIC AMENDMENTS

The application of organic amendments to soils may cause agronomic and environmental problems if not properly understood and managed. Potential problems, elaborated in chapters dealing with specific amendments, are briefly outlined below:

1. Net immobilization of nitrate and ammonium may occur when residues with very high carbon to nitrogen ratio are added to soils. This effect (section 2.3.1), may limit nitrogen availability to plants unless supplemental nitrogen is added to the soil.
2. Heavy applications of amendments may cause soil physical problems resulting in poor seedbed preparation. If the waste contains a great deal of water, a drying interval is required to prevent soil compaction from tillage or seeding equipment.
3. Heavy applications of fluid waste may result in surface runoff, which may pollute surface water supplies and result in eutrophication.
4. Odour problems may cause conflicts between urban residents and farmers and may sometimes restrict the use of organic amendments.
5. The addition of organic materials to wet soils may cause some losses of nitrogen due to denitrification. Denitrifying bacteria under anaerobic conditions use soil organic matter as an energy source to convert nitrates to gaseous nitric oxide, nitrous oxide, and nitrogen, which are lost from the soil to the atmosphere. The generation of

compounds such as nitrous oxide is not only an economic loss but an environmental problem, because this compound contributes to potential ozone depletions, and global warming.

6. Some wastes, such as manures and sewage sludge, may contain high levels of soluble salts. The leaching of salts may contaminate groundwaters, and therefore upper limits on amendment applications may be based on soluble salt content. High nitrate concentrations in drinking water has a negative impact on human and livestock health.
7. Humic substances may leach into water supplies and react with chlorine (added in water treatment) to form toxic organic compounds (Stevenson 1986).
8. Sewage sludge contains variable amounts of heavy metals, which may accumulate in soils, leach into groundwater, or be taken up by plants. Toxicity to plants, or to animals and humans that feed on plants grown in contaminated soils are important concerns. Microbial alteration of heavy metals such as mercury, arsenic, and selenium in polluted soils may result in the formation of toxic organic compounds (Alexander 1977). Sewage sludge also contain microbiological pathogens which may enter the food chain if sludge are not adequately processed.
9. Organic amendments do not provide a permanent increase in soil organic matter. The establishment of plants on the soil is important for the long-term maintenance of adequate soil organic matter levels. Growing plants provide an ongoing input of organic matter to the soil.

3. TYPES AND EFFECTIVENESS OF ORGANIC AMENDMENTS

3.1 ANIMAL MANURE

3.1.1 Types

Farm produced animal wastes include faeces, urine, slurry (Widdowson 1987) and bedding materials such as straw and sawdust. Manure consists of bedding, faeces and urine. To encourage anaerobic fermentation manure can be rotted in stockpiles. To obtain aerobic oxidation manure can be composted, usually by windrowing with regular turning. Additions of manure can build up the organic content of soil. Urine is in effect a liquid nitrogen-potassium fertilizer which, when added to the soil, supplies plant nutrients, but does not build up the organic content. Slurry is a semi-liquid product composed of faeces, urine, and waste-water, and, like urine, is a source of nitrogen.

Weight for weight, rotted or composted manure is more valuable than fresh or raw manure as a soil additive (MacLean and Hore 1979). Rotted or composted manure contains a higher percentage of plant nutrients in a more readily available form and usually has a lower moisture content than raw manure. However, some nutrients are lost in the rotting and composting processes. Fresh manure, because of its coarseness, has been shown to be more suited to improving physical conditions of clay and loam soil. Rotted and composted manure, because it improves soil aggregation and moisture holding capacity, is more suited to improving physical conditions of sandy soils (MacLean and Hore 1979).

Composted manure has a lower moisture content and a more stabilized nutrient content than raw manure (Weston and Oien 1984). Benefits of composting over direct application of raw manures include:

1. Stabilization of organic matter forms;
2. Conservation of plant nutrients and improvement of nutrient availability to plants, because the carbon to nitrogen ratio is lowered especially where bedding materials are included in manure;
3. Ease of handling, less potential pollution problems due to spillage, and reduced odour with lower moisture content;

4. Reduced volume and mass of material, resulting in decreased transportation costs; and
5. Destruction of most weed seeds.

Animal bedding material is frequently a component of manures. The bedding could include straw, hay, wood wastes, or even newspapers in the case of poultry manure. In general, such additions increase the carbon to nitrogen ratio of the final rotted or composted product and nitrogen immobilization may occur when manure is applied to the soil.

3.1.2 Sources

On average, the amount of manure produced in a year by typical adult farm animals range from 10 t for a horse, 13 t for a cow, 1 t for a sheep, 1.8 t for a hog and 0.05 t for a laying hen (Agriculture Canada 1980). Because there are an estimated 4 700 000 cattle, 306 000 sheep, 1 730 000 hogs, and 8 700 000 chickens in Alberta (Alberta Agriculture 1991a), manure production in Alberta could be as high as 65 million Mg annually.

In Alberta, sources of manure include farmyards, feedlots, dairy farms, and broiler or laying houses. Cattle manure is an important source, not only in terms of nutrients, but because the volume produced per animal is high and because there are large numbers of animals in the province. In southern Alberta in particular, feedlots produce large quantities of manure year round. In some places disposal is a problem.

Locally processed, bagged, dried, and composted sheep and cattle manure are available commercially from many garden centres in the province. Feedlot manure is composted and distributed commercially by the Mg by at least one operator in southern Alberta.

3.1.3 Chemistry

3.1.3.1 Chemistry of manure.

3.1.3.1.1 Organic carbon, organic matter, and carbon to nitrogen ratios of manure. Most available studies have focused on determining the usefulness of animal wastes as soil amendments or potential soil fertilizers, rather than on monitoring changes in quantity of organic matter or organic carbon in manure. However, several studies have measured organic matter content as part of determining the characteristics of manure (summarized in Table 4).

Table 4. Summary of papers on chemical characteristics of animal manures.

Reference	Location	Type of Manure	Organic Matter %	Organic Carbon %	C/N Ratio	pH	Comments
Chae and Tabatabai 1986	Iowa	-Chicken		38.0		7.7	Analyses on air dried basis
		-hog		43.3		6.2	
		-horse		44.2		7.7	
		-cow		47.3		5.9	
Ndayegamiye and Cote 1989	Quebec	-Solid cattle		8.2	20.5:1		
		-pig slurry		2.9	5.8:1		
Widdowson 1987	United Kingdom	-Cattle	5.5		20:1 for cattle manure		
		-pig	6.0				
		-hen	11.0				
Petrikova 1980	Czechoslovakia	Semi-liquid					
		-cattle	3.9			7.1	
		-pig	2.4			6.7	
		-poultry	7.2			6.8	
Sommerfeldt et al. 1988; Chang et al. 1991	Lethbridge Alberta	Cattle feedlot	Ranged from 9.1% to 41.9%, average 28.4% between 1973 and 1983.		Ranged from 7.5:1 to 13.3:1 (dry weight basis) over 7 years	7.2 average over 11 years	
Sommerfeldt and MacKay 1987	Lethbridge Alberta	-Cattle feedlot mixed with softwood shavings	33.8% averaged over 7 years		16.5:1 with wood shavings	8.1 with wood shavings	
		-Cattle feedlot without shavings	25.1% averaged over 7 years		9.8:1 without wood shavings	7.3 without wood shavings	
Paul and Beauchamp 1989	Ontario	Various animal manure slurries, solid, rotted and composted animal manures				varied from 6.3 for hog slurry to 8.5 for composted animal manure. Most fell within 7.0 to 7.6 range	
McCalla 1974	Nebraska	Beef cattle slurry				7.3	

The organic carbon compounds found in manure are related to the feed the animals consume. Easily decomposed plant materials such as sugars and celluloses are broken down and digested, leaving the more resistant compounds to be excreted. Microbial tissue and waste products are also found in manure, especially from ruminants (Brady 1990).

It is difficult to compare the organic carbon and organic matter content of manure between different studies, as the moisture content at which the analyses were carried out is usually not mentioned (see for example Chang et al. (1991) and Sommerfeldt et al. (1988)). Addition of bedding materials (Sommerfeldt and MacKay 1987) may increase the organic matter content of the manure, but bedding generally decomposes at a much slower rate than the animal wastes mixed with it, and is not a good source of plant nutrients.

The carbon to nitrogen ratio of solid manures depends on the animal of origin, other materials incorporated into it, and handling. Carbon to nitrogen ratios vary from 20.5:1 for solid cattle manure, to 5.8:1 for a pig slurry have been found in Quebec (Ndayegamiye and Cote 1989). In Alberta, carbon to nitrogen ratios of feedlot manure have been found to range from 7.5:1 to 13.3:1 (dry weight basis) (Sommerfeldt et al. 1988). Adding softwood shavings as bedding material, increase the carbon to nitrogen ratio of cattle manure from an average of 9.8:1 to an average of 16.5:1 (Sommerfeldt and MacKay 1987).

3.1.3.1.2 pH. The pH of manure depends on the origin of the manure, the type of bedding materials included, and whether the manure is in a slurry or solid form. For hog manure, reported pH values are 6.2 in Iowa (Chae and Tabatabai 1986), 6.3 for hog manure slurry in Ontario (Paul and Beauchamp 1989), and 6.7 in Czechoslovakia (Petrikova 1980). In Alberta, average pH of cattle feedlot manure has been found to be 7.2 (Chang et al. 1991). Adding softwood shaving bedding materials to cattle manure, has been found to increase the pH from 7.3 to 8.1 (Sommerfeldt and MacKay 1987).

3.1.3.1.3 Nutrients. Nutrient content of manure varies with type of manure, amount of bedding, and type of storage. Brady (1990) notes that in general, three-quarters of the nitrogen, four-fifths of the phosphorus, and nine-tenths of the potassium ingested in feeds are voided by animals. He also notes that one-half the nitrogen, most of the phosphorus and two-fifths of the potassium are found in the solid portion of manure. The nutrients in the liquid urine portion of the manure are more readily available, however, so that when storing and handling manure, care must be taken to minimize loss of liquids.

Table 5 shows nutrient composition of fresh manure from animals supplied with ample bedding. Percentage of nitrogen and potassium is higher in urine than in faeces, whereas percentage of phosphorous is higher in faeces (MacLean and Hore 1979). Nitrogen in urine (mostly urea) quickly converts to plant available forms, whereas nitrogen in faeces is more slowly changed because it is bound up in undigested feed. Horse, pig, sheep, and poultry manures contain more nitrogen, phosphorus, and potassium than cow manure.

The nutrient composition of manure is also partly dependent on the kind of feed the animal eats. If the amount of protein in feed is increased, the amount of nitrogen in manure also increases (MacLean et al. 1983). Growing animals generally receive feed high in nitrogen. Therefore, the amount of nitrogen in manure is generally higher from steers than from dairy cows, and higher for broilers than for laying hens.

The quantity and quality of bedding material can affect the degree of retention of urine in the manure as well as affecting the amount of nitrogen, phosphorus and potassium present (Table 6). Addition of bedding materials increases the carbon to nitrogen ratio of manure. Too much straw or sawdust in manure may result in immobilization of nitrogen when manure is added to the soil.

One of the benefits of composting manure with bedding materials is that the carbon to nitrogen ratio of the material is lowered, reducing or eliminating problems of nitrogen immobilization. Composting of manure also conserves many of the nutrients and improves the availability of these nutrients to plants (Table 7; Weston and Oien 1984). However, some losses of nitrogen occur during the composting process if aeration is poor.

3.1.3.1.4 Salts. The salt content of manure is of concern if the material is to be applied to saline or sodic soils, or if numerous applications are to be made to one area. Table 8 presents soluble salt concentrations for cattle feedlot manure for two different studies in Lethbridge, Alberta (Chang et al. 1991; Sommerfeldt and MacKay 1987). Average concentrations of salts were similar in both studies. EC and SAR levels were high for both sources of manure, although the addition of wood shavings as bedding material appears to have reduced the levels somewhat through dilution. Salt accumulations in cattle manure reflect the salt concentration in cattle feed, because nearly all of the sodium and chloride consumed by cattle is excreted (Sweeten and Mathers 1985).

Table 5. Composition of fresh manure produced by animals provided with ample bedding.[a]

Source and Components of manure	Nutrient Content (wet weight basis) Nitrogen (as N) %	kg/Mg	Phosphorous (as P_2O_5) %	kg/Mg	Potassium (as K_2O) %	kg/Mg
Horse, total mixture	0.66	6.6	0.23	2.3	0.68	6.8
Cow, total mixture	0.57	5.7	0.15	1.5	0.53	5.3
Pig, total mixture	0.56	5.6	0.32	3.2	0.52	5.2
Sheep, total mixture	0.90	9.0	0.34	3.4	1.00	10.0
Poultry, faeces and urine	1.47	14.7	0.50	5.0	0.40	4.0

[a] Source: MacLean and Hore (1979).

Table 6. Nutritive value of bedding.[a]

Bedding	Nutrient content % Nitrogen (N)	Phosphorous (P_2O_5)	Potassium (K)
Straw	0.5	0.2	1.0
Sawdust and shavings	0.4	0.3	0.7
Peat moss (air-dried)	0.8	trace	trace
Muck and peat (air-dried)	1.5	0.2	trace

[a] Source: MacLean and Hore (1979).

Table 7. Concentrations of selected nutrients in composted manures.

Parameter	Fresh Feedlot Manure[a]	Composted Feedlot Manure[a]	Composted Feedlot Manure from Alberta[b]
Moisture %	50 to 80	19 to 25	24 to 30
Nitrogen %	0.9 to 1.5	2.0 to 3.0	1.0 to 1.5
Phosphorus %	0.3 to 0.5	0.9 to 1.2	0.7 to 1.8
Potassium %	0.6 to 1.8	2.8 to 3.5	1.9 to 2.2
Sulphur %	0.2 to 0.3	0.4 to 0.6	0.5 to 2.5
Zinc (ppm)	82 to 125	156 to 226	nd[c]

[a] Source: Adapted from original table in Weston and Oien (1984).

[b] Source: Dwight Perry, Corban Enterprises, Coaldale, Alberta, letter dated November 5, 1992.

[c] Not determined.

Table 8. Average salt concentrations for cattle feedlot manure in Alberta.[a]

Parameter	Manure[b]	Manure with shavings[c]	Manure without shavings[c]
EC (dS/m)	23.0	16.7	25.0
SAR	21.8	16.1	22.2
Na (mol/kg)	17.2	13.0	14.9
Ca and Mg (mol/kg)	3.5	2.4	2.9
SO_4-S (mol/kg)	3.2	3.9	4.3
Cl (mol/kg)	23.8	20.1	21.8
HCO_3 (mol/kg)	na[d]	14.8	12.8

[a] Source: Adapted from original tables in Chang et al. (1991) and Sommerfeldt and MacKay (1987).

[b] Averaged over 11 years (Chang et al. 1991).

[c] Averaged over 7 years (Sommerfeldt and MacKay 1987).

[d] Not available.

Little other information appears to be available on the salt content of manures. Petrikova (1980) reported % Calcium, Magnesium, and Sodium for pig, cattle, and poultry manures from Czechoslovakia, but neither EC nor SAR values were reported, making comparisons with the Alberta studies difficult.

3.1.3.1.5 Micronutrients and heavy metals. Micronutrients in manure include iron (Fe), manganese (Mn), copper (Cu), cobalt (Co), molybdenum (Mo), boron (B), chlorine (Cl), and selenium (Se). Non-nutrients (heavy metals) include nickel (Ni), cadmium (Cd), lead (Pb), mercury (Hg), and arsenic (As) (Webber and Webber 1983). Table 9 presents a comparison of selected micronutrients and heavy metals in Canadian soils and animal manures.

Generally, except for Cu in manure from hogs receiving Cu supplements, and possibly in some poultry manures (McCalla 1974), manures from poultry, sheep, cattle and hogs have similar concentrations of elements (Webber and Webber 1983). Zinc may be elevated in manures if this element has been used as a feed additive (Stevenson 1986).

3.1.3.1.6 Organopollutants. Organopollutants include pesticide residues in feed, feed and water additives, insecticides, and medicines (Frank 1983). It has been suggested in the literature that potentially hazardous organic compounds that have been consumed by, or injected into animals may be voided in manure. Sometimes contaminated bedding materials are incorporated into manures as well.

3.1.3.2 Effect of manures on soil chemistry. The effect of animal manure on soil chemistry depends on the nature and origin of the manure, the amount of manure, and the number of applications. In general, manure increases soil organic matter content, total nitrogen, and available phosphorus. Because manure often contains lower ratios of phosphorus to nitrogen and phosphorus to potassium than commercial fertilizers, it may be necessary to supply additional phosphorus when applying manure to the soil (Brady 1990). However, because phosphorus is much less mobile than nitrogen, it can build up in the soil with repeated applications of manure. Possible undesirable effects of repeated applications of high rates of manure over long periods of time are increased soil salts, heavy metals, and organopollutants. Papers discussing the effects of manure applications on soils are summarized in Tables 10a, 10b, and 10c.

Table 9. Selected micronutrients and non-nutrients in Canadian soils and manures (mg/kg, dry weight).[a]

	Manure		Soil	
Trace Element	Range	Average	Range	Average
Fe	240 to 1 075	580	500 to 122 000	26 000
Mn	6 to 549	166	19 to 1 600	511
Zn	30 to 450	117	8 to 275	78
Cu	6 to 41	15	2 to 78	23
Ni	0.3 to 4.7	2.8	1 to 86	21
Co	0.3 to 4.7	1.2	1.7 to 60	21
Cr	1.1 to 5.2	3.0	5 to 141	44
Mo	0.7 to 15.8	2.5	0.3 to 0.9	0.6
B	4.6 to 52	20	na[b]	na
Se	0.10 to 1.48	0.43	0.02 to 2.2	0.3
Cd	0.25 to 1.3	0.5	<0.3	<0.3
Pb	2.5 to 27	9.3	1.9 to 51	20
Hg	na	na	<0.005 to 4.6	0.08

[a] Source: Webber and Webber (1983).

[b] Not available.

Table 10a. Summary of papers on the effects of manure on soil organic matter % (OM%), carbon to nitrogen ratio (C:N), pH, and nutrient status.

Author	Year	Location	Manure Type	Application Rate	Effects on Soil
Campbell et al.	1986	Saskatchewan	barnyard manure	13.4, 20.2 and 26.9 Mg/ha, every 3 years for 36 years.	Organic carbon increased from 2.35% to 2.61% and 2.58% for the lowest and highest rates. Increase in soil P, all treatments.
Chang et al.	1990	southern Alberta	cattle feedlot	0 to 90 Mg/ha on non-irrigated 0 to 120 Mg/ha on irrigated, both annually for 11 years.	All treatments increased OM%. Very slight decrease in pH for both irrigated and non-irrigated.
Dormaar et al.	1988	southern Alberta	feedlot	30 Mg/ha every 2 years for 6 years.	Increased OM% on artificially eroded land. Increased total N, available P.
Dubetz et al.	1975	southern Alberta	unknown	24 Mg/ha, once every 4 years for 16 years.	Increase in OM% from 2.62% to 2.83%, manure only; Increase in OM% from 2.62% to 2.97%, manure and N fertilizer. Increased N, P and K levels.
Mathers et al.	1972	Texas	unknown	0 to 224 Mg/ha (100 tons/acre) per year for 3 years.	No change in OM% at 10 and 20 tons/acre per year; increase in OM% at 112 and 224 Mg/ha per year.
Mathers and Stewart	1981	Texas	unknown	22 Mg/ha (10 tons/ac) and 67 Mg/ha (30 tons/ac), both 9 applications over 11 years.	OM% increase from 2.0% to 3.2% on 22 Mg/ha treatment, and from 2.0% to 4.5% on 67 Mg/ha application.
Ndayegamiye and Cote	1989	Quebec	solid cattle and pig slurry	20, 30 and 60 Mg/ha cattle manure every 2 years for 10 years; 60, and 120 m^3/ha pig slurry annually for 10 years	No change in soil C:N ratio with either treatment. Organic carbon % increased at highest rates of both amendments. No change in soil pH or total N content of soil; CEC of cattle manure treatment was higher than of pig slurry treatment.
Sommerfeldt and MacKay	1987	southern Alberta	cattle manure with and without wood shavings.	50 Mg/ha annually for 7 years.	No difference in OM% or C:N ratio between manure additions with and without shavings. Decreased NO_3-N, total N and available P on manure + shavings compared to manure only treatment.
Sutton et al.	1984	USA	pig slurry	90, 180, and 270 Mg/ha (wet) annually for 3 years.	Soil NO_3-N levels increased each year of application, but was depleted after 1 year with no additions. Soil P increased with each year of application, but was not depleted after 1 year with no additions.
Unger and Stewart	1974	Texas	cattle feedlot	0 to 269 Mg/ha (120 tons/ac) for 4 years.	50% and 100% increase in OM% at 22 and 134 Mg/ha respectively.

continued...

Table 10a. Concluded.

Author	Year	Location	Manure Type	Application Rate	Effects on Soil
Robertson	1983	Breton, Alberta	barnyard	9 Mg/ha/year for 50 years	Increased % OC from 1.3 on controls to 1.8 on manure only plots, 2.0 on manure plus NPK plots.
Ridley and Hedlin	1968	Manitoba	unknown	9 Mg/ha before every crop for 37 years	Increase % OC from 3.0 on controls to 3.3 on treated plots.

Table 10b. Summary of papers on the effects of manure on soil salinity and sodicity.

Author	Year	Location	Manure Type	Application Rate	Effect on Soil
Chang et al.	1990	southern Alberta	cattle feedlot	0 to 90 Mg/ha on non-irrigated 0 to 120 Mg/ha on irrigated, both annually for 11 years.	Very slow but linear increase with time in EC and SAR.
Mathers et al.	1972	Texas	feedlot	0 to 224 Mg/ha (100 tons/ac) per year for 3 years.	No salt toxicity problems after 3 years, but increase in Na.
Sutton et al.	1984	USA	pig slurry	90, 180, and 270 Mg/ha (wet) annually for 3 years.	No salt toxicity problems after 3 years.

Table 10c. Summary of papers on the effects of manure on micronutrients, heavy metals, and organopollutants.

Author	Year	Location	Manure Type	Application Rate	Effects on Soil
Costa et al.	1974	South America	cattle	unknown	Picloram toxicity reported on manure amended crops.
Frank	1973	Ontario	unknown	unknown	Picloram toxicity reported on manure amended crops.
Frank et al.	1976	Ontario	unknown	unknown	No elevation of soil heavy metal contents after manure use.
Warman	1980	Nova Scotia	pig, chicken, dairy	liquid pig; 33 750 to 67 500 L/ha dairy; 15 to 30 Mg/ha chicken; 5 to 10 Mg/ha liquid dairy; 75 000 L/ha liquid chicken; 25 00 L/ha	Did not contribute significantly to Cu, Mn and Zn in soils or crops.
Webber and Webber	1983	Canada	various	unknown	No buildup of Fe, Mn, Ni, Cr or Co with manure use. Zn, Cu, Pb, Cd, Mo and Se could build up with excessive rates of application over many years. Cu could build up with some pig manures over time.

3.1.3.2.1 Soil organic matter, pH, and nutrient status. Increases in soil organic matter or organic carbon content with increased manure application were found in the majority of both short and long term studies as rates or numbers of applications of manure increased, and else where in North America, regardless of manure or soil type (Table 10a). Two studies, one in Texas and one in Quebec, found that soil organic matter content increased only at higher rates of application (Mathers et al. 1972; Ndayegamiye and Cote 1989). Some studies noted that soil organic matter content was higher on plots treated with both manure and commercial fertilizers, compared to plots treated with manure alone (Dubetz et al. 1975; Robertson 1983). Adding soft wood shavings to manure had no effect on soil organic matter content (Sommerfeldt and MacKay 1987). Soil carbon to nitrogen ratios did not change significantly with the addition of manure (Ndayegamiye and Cote 1989), nor did the addition of softwood shavings to the manure treatment (Sommerfeldt and MacKay 1987).

The effect of manure additions on soil pH is not consistent among studies. Chang et al. (1990) and Chang et al. (1991) found a very slight decrease in soil pH after 11 yearly applications of cattle manure in southern Alberta. Over the very long term, the significance of a decrease of this magnitude is uncertain. Sommerfeldt et al. (1973, cited in Chang et al. 1990) for example, found no evidence of decreased pH in a field that had been treated with manure yearly for 70 years. In Quebec, Ndayegamiye and Cote (1989) found no change in soil pH after treatment with manure for 10 years.

Increases in total nitrogen, nitrate (NO_3), total phosphorus, available phosphorus, soluble sodium, calcium plus magnesium, sulphate (SO_4), bicarbonate $(HCO)_3$, and zinc were found after 11 yearly additions of manure to soils in southern Alberta. However, there was minimal effect on soil ammonium (NH_4) and copper (Chang et al. 1990, 1991). Campbell et al. (1986), Dormaar et al. (1988), and Dubetz et al. (1975), all working on the Canadian prairies, found increases in nitrogen, phosphorus, or potassium. Elsewhere, results are less consistent. Ndayegamiye and Cote (1989) found no change in total nitrogen in Quebec; Sutton et al. (1984) found that nitrate-nitrogen and phosphorus increased after each application of manure, but that nitrate-nitrogen was depleted after only one crop with no additions. Sommerfeldt and MacKay (1987) found that including softwood shavings with manure applications decreased nitrate-nitrogen, total nitrogen, and available phosphorus compared to manure only treatments.

3.1.3.2.2 Soil salinity and sodicity. Studies examining changes in soil salinity and sodicity following long term applications of animal manures are summarized in Table 10b. In southern

Alberta, Chang et al. (1990), working with irrigated and non-irrigated clay loam textured Dark Brown Chernozemic soils, found that eleven annual applications of cattle feedlot manure resulted in a very slow, linear increase in both soil EC and SAR over time. Although the authors concluded that the sustained agricultural production of this land with annual application of manure was in question, it should be noted that their figures showed an increase in EC of 1 dS/m in 200 to 300 years (irrigated and non-irrigated), and an increase of one SAR unit in 400 to 700 years on irrigated land and 600 to 900 years on non-irrigated land, indicating only extremely long term concerns.

Increases in soil salinity and/or sodicity were also reported in the U.S.A. by Mathers et al. (1972) and Sutton et al. (1984). Whether or not crops were affected would depend on the rates at which the salts could be leached from the root zone of the soil.

3.1.3.2.3 Micronutrients, heavy metals, and organopollutants. Studies investigating the effects of the addition of manure on levels of micronutrients, heavy metals, and organopollutants in soil are summarized in Table 10c.

Webber and Webber (1983) reported that concentrations of most elements in soils were similar to or higher than those in manure (Table 9). Fe, Mn, Ni, Cr, or Co are not expected buildup to toxic concentrations over time with manure applications. Zn, Cu, Pb, Cd, Mo, and Se could build up if excessive rates of manure were applied over many years. Warman (1990) found that additions of dairy, chicken and pig manures on sandy and loam soils in Nova Scotia did not significantly increase micronutrient concentrations (Cu, Mn and Zn) in soil or barley and corn crops.

There is little information in the literature evaluating the effects of adding manure contaminated with organopollutants to the soil. Potentially, soils have the capacity to adsorb or decompose many of these compounds; however, contaminated manure should be added with caution. One case of picloram toxicity has been reported in crops treated with manure mixed with contaminated bedding materials (Frank 1983). Costa et al. (1974, cited in Frank 1983), also document a situation in which manure from animals fed on picloram-treated feed proved toxic to plants after addition to soil. There is a clear need for further research focusing on the fate of these chemicals in soils and on their uptake by plants.

3.1.4 Physical Properties

Little information is available on the physical properties of animal manure itself; most studies have focused on the effects on soil physical properties of manure additions. The beneficial effect of manure application on soil physical properties is well established, particularly for soils with low organic matter content, such as Luvisolic soils.

3.1.4.1 Physical properties of manure

3.1.4.1.1 Form. Manure can be classified as a solid, semi-solid or liquid depending on the moisture content (West 1981). Solid manure contains less than 85% moisture and is non-flowing. Semi-solid manure contains 85% to 90% moisture and is more difficult to handle. Liquid manure contains moisture in excess of 90%. Use of liquid manure has become more popular due to its ease of handling. Composted manure is normally dry and in a granular form.

3.1.4.1.2 Odour and gases. Odours generally occur if manure is not composted. Hydrogen sulphide, ammonia, carbon dioxide, and methane are produced under anaerobic conditions (West 1981). Hydrogen sulphide is toxic and heavier than air; it collects in manure storage facilities. Ammonia is most likely to occur with solid floor operations. Carbon dioxide is odourless, non-toxic and heavier than air; it collects in manure pits. Methane is also odourless, but is lighter than air. When manure is composted under aerobic conditions, the gases produced are relatively odourless and are mostly carbon dioxide.

3.1.4.1.3 Moisture content. Moisture contents of fresh manure has been determined to be 79% for dairy cattle, 80% for finishing cattle, 75% for hogs, 60% for horses, and 65% for sheep (Loehr 1968, cited in McCalla 1974). However, there can be much variability. For example, moisture content of cattle feedlot manure in southern Alberta varied from 53.1% to 110.1% for the years 1973 to 1983 for the same feedlot (Sommerfeldt et al. 1988).

3.1.4.2 Effect of manure on soil physical properties. Addition of animal manure to soils generally results in an increase in water stable aggregates, decrease in bulk density, and an improvement of many soil water characteristics, all of which affect plant growth. The proportion of large pores is increased, which increases the infiltration and percolation of water, as well as soil aeration. Root penetration is improved, particularly on fine textured soils, and soils become less prone to water erosion (MacLean et al. 1983). Decreased bulk density generally improves growing conditions, particularly in moderately fine to fine textured soils. Soil water-holding capacity, permeability, and porosity all increase with a decrease in bulk density. These factors are especially important in drought-prone areas of Alberta.

Tables 11a, 11b, and 11c summarize papers discussing the effects of additions of animal manure on soil physical properties.

3.1.4.2.1 Soil structure. Manure applications improve soil structure by increasing proportions of water stable aggregates, resulting in improved water infiltration rates and aeration (Sweeten and Mathers 1985).

Increased aggregate stability, increased water stable aggregates, or increased mean diameter of water stable aggregates with additions of manure, have been reported by Bhatnagar (1979) in Ontario, Cross and Fischbach (1973) in Nebraska, Dormaar et al. (1988) in southern Alberta, and Unger and Stewart (1974) in Texas. Both Bhatnagar (1979) and Cross and Fischbach (1973) also noted that increased aggregate stability was most noticeable at high rates of manure application. Bhatnagar (1979) speculated that a similar effect could occur with repeated applications of manure at lower rates. Increased soil porosity was reported by Pagliai et al. (1981, cited in Sweeten and Mathers 1985), and Unger and Stewart (1974, cited by Sweeten and Mathers 1985).

Decreased surface soil crusting was reported by Hornick (1988). She found that seedling emergence on fertilized controls was much lower than on plots treated with an organic amendment. Fertilized plots with manure treatments had slightly lower surface soil strengths than fertilized plots with sludge treatments. Figure 6 compares surface strength on soils with manure and composted sewage sludge amendments. The zero rate represents fertilized control plots.

In Alberta, Bateman and Chanasyk (1992) compared manure and peat as amendments combined with deep ripping on reconstructed coal strip mine soils in central Alberta. The manure amended soil improved soil quality by improving soil consistence, increasing plastic limit, increasing aggregation, reducing crusting, and lowering bulk density of topsoils compared to soil that was only deep ripped.

3.1.4.2.2 Soil bulk density. Most studies report that additions of animal manure decrease soil bulk density. These include Cross and Fischbach (1973) and Cross et al. (1973), both cited in

Table 11a. Summary of papers on the effects of manure on soil structure.

Author	Year	Location	Manure Type	Application Rate	Effect on Soil
Bateman and Chanasyk	1992	Central Alberta	unknown	275 Mg/ha, after deep ripping minespoil	General improvement of soil physical properties including aggregation and tilth.
Bhatnagar	1979	Ontario	liquid poultry manure	0 to 400 Mg/ha (laboratory study)	Increased aggregate stability most noticeable at higher rates.
Cross and Fischbach	1973	Nebraska	cattle feedlot	0 to 582 Mg/ha (260 tons/ac)	Increased mean diameter of water-stable aggregates, especially at high rates of application.
Dormaar et al.	1988	southern Alberta	cattle feedlot	30 Mg/ha every 2 years for 6 years	Increase in water-stable aggregates.
Hornick	1988	Maryland	cattle feedlot	40, 80 and 160 Mg/ha annually for 2 years	Decreased soil surface crusting with all manure treatments.
Pagliai et al.	1981	unknown	unknown	49 Mg/ha (22 tons/ac)	84% increase in soil porosity on a sandy loam.
Unger and Stewart	1974	Texas	cattle feedlot	0 to 269 Mg/ha (120 tons/ac) for 4 years	Increased % of large water-stable aggregates. Increased porosity.

Table 11b. Summary of papers on the effects of manure on soil bulk density.

Author	Year	Location	Manure Type	Application Rate	Effect on Soil
Campbell et al.	1986	Saskatchewan	barnyard	13.4 to 26.9 Mg/ha every 3 years for 36 years	No change in bulk density.
Cross and Fischbach	1973	Nebraska	cattle feedlot	0 to 582 Mg/ha (260 tons/ac) dry.	At 269 Mg/ha, bulk density reduced from 1.30 to 1.22 g/cm^3. At 582 Mg/ha, bulk density reduced from 1.3 to 1.01 g/cm^3.
Hafez	1974	unknown	various	1% to 10% of soil mass.	Bulk density decreased by 4%, 13% and 23% at rates of 2%, 5% and 10% of soil mass respectively.
Mathers and Stewart	1981	Texas	unknown	22 Mg/ha (10 tons/ac) and 67 Mg/ha (30 tons/ac), both 9 applications over 11 years.	Bulk density decreased by 3% to 4% at the lower rate, and by 10% at the higher rate.
Sommerfeldt and Chang	1985	Alberta	cattle feedlot	0 to 90 Mg/ha on nonirrigated soil and 0 to 180 Mg/ha on irrigated soil	Decreased bulk density with increasing rates of manure at 0 to 15 cm for both soils and for the irrigated soil only at 15 to 30 cm.
Unger and Stewart	1974	Texas	cattle feedlot	0 to 269 Mg/ha (120 tons/ac) for 4 years	Decrease in bulk density from 3% for 22 Mg/ha application, to 18% at 269 Mg/ha application.
Bateman and Chanasyk	1992	Central Alberta	unknown	275 Mg/ha, after deepripping minespoil	Decrease in bulk density from 1.15 g/cm^3 on ripped treatment and 1.12 g/cm^3 on unripped control, to 0.90 g/cm^3

Table 11c. Summary of papers on the effects of manure on soil water characteristics.

Author	Year	Location	Manure Type	Application Rate	Effect on Soil
Hafez	1974	unknown	various	1% to 10% of soil mass	Increased hydraulic conductivity.
Mathers and Stewart	1981	Texas	manure	22 Mg/ha (10 tons/ac) and 67 Mg/ha (30 tons/ac), both 9 applications over 11 years.	Increased saturated hydraulic conductivity.
Sommerfeldt and Chang	1985	Alberta	cattle feedlot	0 to 82 Mg/ha (90 tons/ha) on nonirrigated soil, 0 to 163 Mg/ha (180 tons/ha) on irrigated soil	Decreased plant available water content.
Unger and Stewart	1974	Texas	cattle feedlot	0 to 269 Mg/ha (120 tons/ac) for 4 years	Increased water permeability and infiltration rates.
Campbell et al.	1986	Saskatchewan	barnyard	13.4 to 26.9 Mg/ha every 3 years for 36 years	No change in hydraulic conductivity.

Sweeten and Mathers (1985), Hafez (1974), Unger and Stewart (1974) cited in Sweeten and Mathers (1985), and Mathers and Stewart (1981) in Texas.

In southern Alberta, Sommerfeldt and Chang (1985) found that at depths of 0 to 15 cm, soil bulk density decreased with increasing rates of manure, on both irrigated and dry- land soils. Lowest bulk densities occurred where manure was incorporated by cultivator. At depths of 15 to 30 cm, bulk density decreased with increasing rates of manure only for the irrigated soil, and lowest bulk densities occurred where manure was incorporated by plow. In contrast, a single long term study in Saskatchewan reported no effect of manure on soil bulk density on a clay-textured Black Rego Chernozemic soil (Campbell et al. 1986).

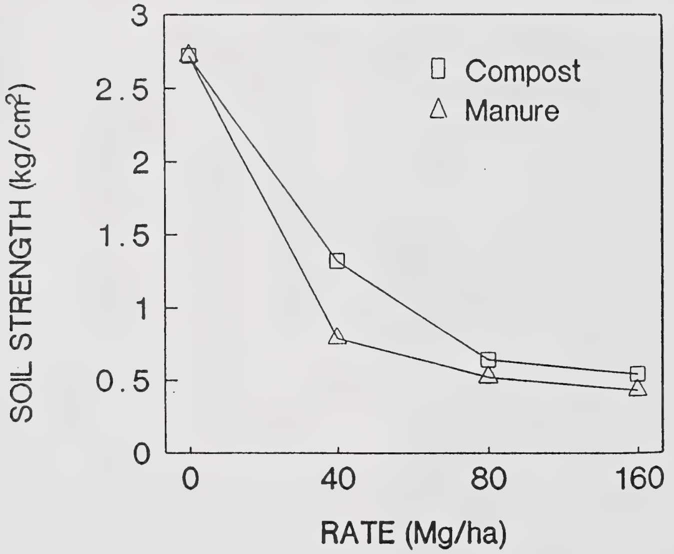

Figure 6. Surface crusting strength changes with rate of manure addition.[a]

[a] Source: Adapted from original figure in Hornick (1988).

3.1.4.2.3 Soil water characteristics. In a long term study in Texas, increased water infiltration rates reported on a sandy loam soil were thought to be the result of reduced soil bulk density and increased soil porosity with increasing rates of manure addition (Unger and Stewart 1974, cited by

Sweeten and Mathers 1985). Increased saturated hydraulic conductivity and water holding capacity of soils amended with manures have been reported by Hafez (1974), Hornick (1988), and Mathers and Stewart (1981, cited by Sweeten and Mathers 1985). However, decreased plant available water was reported from a study in southern Alberta, in which high rates of manure were added to irrigated and nonirrigated soils (Sommerfeldt and Chang 1985)

3.1.4.3 Effect of manure on soil biology. Manure application to soil generally stimulates soil biological activity if the soil remains well aerated. The partially decomposed and altered plant products in manure supply energy to the soil microbial community. This in turn stimulates soil fauna which feed on the smaller organisms. The improved physical properties of soil after additions of manure also improve conditions for biological activity, by increasing the soil's capacity for gas exchange and its moisture holding capacity. However, if manures, especially slurries, are applied at excessive rates, the soil may suffer from oxygen deprivation which will reduce the overall biological activity of the soil and will favour anaerobic bacteria.

A potential problem with applying manure to soil is that manures are often a source of weeds. According to Barrington (1991), weed contamination of manure can occur in three ways:

1. The presence of whole weed seeds in the feed material;
2. The dropping of weed seeds by birds and the wind into stored manure; and
3. The use of bedding material which contains weed seeds that make their way into the manure.

To this list, Sutton (1983) adds that some weed seeds remain viable even after passing through the digestive tracts of animals. These problems are reduced if straw bedding is replaced with wood shavings, if pelleted or ground grains are fed to livestock, or if manure is stored under cover and allowed to compost at high (>65°C) temperatures (Barrington 1991).

3.1.4.4 Water quality. According to West (1981) water contamination or pollution can occur through:

1. Direct dumping of manure into surface water;
2. Runoff from feedlot and stockpiles;
3. Overflow from manure storage facilities;
4. Water runoff in the spring following winter application of manure;
5. Seepage from excessively high application rates into ground water; and

6. Lagoons and retention ponds constructed in porous soils.

The factors that are most likely to affect a soil reclamation situation include water runoff after spring breakup if manure has been applied to the land in the winter, and seepage from application of manure at excessive rates.

3.1.5 Application and Timing.

3.1.5.1 Methods. Management practices can help conserve the nutritional value of manure and help prevent water pollution by controlling leaching and runoff of soluble ions. Methods of applying manure to soil include:

1. Daily spreading;
2. Storage and periodic spreading;
3. Subsurface injection; and
4. Sprinkler irrigation.

Daily spreading is a common method of handling manure because it is relatively simple and costs are low (Wooding 1982). However, problems can arise when the weather is unfavourable. For example, applying manure in wet weather conditions can result in soil rutting and compaction. Spreading manure on frozen soils or snow increases the chance of loss during spring runoff. An Ontario study showed that nitrogen and phosphorus concentrations in snowmelt water were highest when manure was applied in winter (Phillips et al. 1981, cited in MacLean et al. 1983). Other problems arise when excessive rates of manure are applied, and when manure must be applied and incorporated into a cropped field during the growing season. Flying insects and odour may cause problems in some cases, particularly in inhabited areas.

Storage of manure prior to spreading allows flexibility in the application schedule. Ideally, manure should be spread and immediately incorporated prior to spring seeding, for maximum availability of nutrients to plants (Wooding 1982). In summer, manure applications are restricted to fallowed land, pastures, grain stubble, and hayfields.

Many of the problems associated with applying fresh, solid manure to fields are solved by using composted manure. Because composted manure is dry and granular, it can be applied with normal fertilizer spreading equipment. There are no odour or insect problems, and weeds are unlikely to be introduced because weed seeds are destroyed at composting temperatures.

Subsurface injection is used to inject liquid manure (<8% solids). Injection should be done in the spring or early summer, at a rate corresponding to crop requirements. One advantage to this method is that the manure can be applied in a field of low-growing crops without damaging plants or causing an odour problem (Wooding 1982).

Sprinkler irrigation can be used to apply diluted liquid waste (<6% solids) that has been collected in large tanks or storage. This method has some limitations. Liquid manure containing unchopped hay, straw, or other bedding materials cannot be pumped through the irrigation sprinkler guns. Because the manure mixture is agitated and then sprayed into the air, up to 30% of the nitrogen can be lost (Wooding 1982). Odours can create additional problems.

3.1.5.2 Rates. Because of the danger of groundwater and surface water pollution, application rates are critical. Chang and Entz (1991), working in southern Alberta, concluded that the impact on groundwater quality of long-term manure additions of up to 3 times the maximum recommended rate for the area, was small under dryland conditions, but had the potential to contaminate groundwater under conditions of high precipitation. Long-term application of high rates of manure on irrigated land could cause nitrate contamination of shallow groundwater. However, Dormaar and Sommerfeldt (1986), also in southern Alberta, noted no adverse agronomic effects after applying manure at triple the recommended rate.

West (1981) indicates that rates of manure application should reflect:

1. Texture and fertility of the soil;
2. Nutrient requirements of the crops to be grown;
3. Nutrient content of manure; and
4. Local climatic factors.

Recommended maximum annual manure application rates for Alberta, shown in Table 12, should not be exceeded, especially in areas of the province that receive higher precipitation, or under irrigation.

Although long-term application of manure may have some detrimental effects on soil quality, most studies indicate that, even at moderate to high rates of application, soil degradation is very slow. For example, Webber and Webber (1983) calculated that very large numbers of manure applications could be made to Ontario soils before attaining the maximum recommended additions of micronutrients and non-nutrients (Table 13). Only spreading hog manure with high concentrations of Cu (1000 mg Cu/kg manure) was believed to be a potential hazard to crop production.

Table 12. Recommended maximum annual application rates for animal manures in Alberta.[a]

	Solid Manure (Mg/ha)		Liquid Manure (kg/ha)	
Soil Zone	Cattle, Hogs	Poultry	Cattle	Hogs
Brown and Dark Brown				
dryland	22 to 27	9 to 13	33 600 to 67 200	11 208 to 44 800
irrigated	56 to 67	22 to 27	89 700 to 112 000	33 600 to 89 700
Black and Grey Wooded	33 to 45	18 to 22	56 000 to 89 700	22 400 to 67 200

[a] Source: Alberta Agriculture (1980).

Table 13. Maximum recommended additions of micronutrients and non-nutrients to Ontario soils and the numbers of manure applications required to attain them.[a]

Element	Maximum Recommended Additions (kg/ha)[b]	Amount applied with 6 Mg/ha dry weight manure (kg)	Number of Applications to Att Maximum Recommended Additions
Arsenic	14	na[c]	na
Cadmium	1.6	0.003	530
Cobalt	30	0.007	4290
Chromium	210	0.018	11 670
Copper	150	0.090	1670
Mercury	0.8	na	na
Molybdenum	4.0	0.015	270
Nickel	32	0.017	1880
Lead	90	0.056	1610
Selenium	2.4	0.003	800
Zinc	330	0.702	470

[a] Source: Webber and Webber (1983).

[b] Source: Adapted from the original table in Ontario Ministry of Agriculture and Food and Ontario Ministry of the Environment (1981).

[c] Not Available.

3.1.5.3 Equipment. Manure solids can be applied to soil with conventional manure spreaders, then disced or plowed into the soil. Solid manure can be moved manually, or by tractor-mounted bucket scrapers, chain or slat conveyors (West 1981). Composted manure in granular form can be spread with a normal fertilizer spreader.

Equipment used to apply manure slurries depends on the total solids content of the slurry (Figure 7, Schofield 1984). Slurries with lower total solids (<10%) can be applied with a pump and manure gun. At higher total solids (>10%), applications are made with buckets, grabs, and spreaders. Runoff from feedlots, or liquids from lagoons, or oxidation ditches may be applied to soil with sprinklers, gravitation irrigation, or direct injection (McCalla 1974).

3.1.6 Costs

For farmers, the main costs of applying manure are for transportation. As fertilizer costs increase, it becomes more economical to use manure (McCalla 1974). The economics of using commercial fertilizers versus hauling manure from feedlots to crop land were studied in Alberta using a computer model (Freeze and Sommerfeldt 1985). The break-even hauling distance was determined to be 15 to 18 km, based on type of machinery, hauling speed, labour use, spreading time, and crop responses. However, an Agriculture Canada economist determined the break-even distance to be 30 km (cited in Climenhaga 1991). The break-even distance in this case was the distance at which the costs of using fertilizer and hauling manure were equivalent. Fertilizer prices, commodity prices, and potential yields were other important factors in calculating break-even costs.

For reclamation uses, manure has other beneficial effects besides its fertilizer value. Increased soil organic matter content, and improved soil physical properties resulting from application of manure to reclaimed sites cannot be duplicated with the use of commercial fertilizers alone, and are difficult to quantify in monetary terms. Economic hauling distances for reclamation should be considerably higher than those for general agriculture. Composted manure is cheaper and easier to transport than raw manure because it is in a dry and granular form.

3.1.7 Longevity of Effects

According to Brady (1990), one-fifth to one-half of the nutrients supplied by animal manures will be recovered by the first crop following application. Much of the remaining nitrogen and phosphorus is held in resistant organic compounds which will be released at rates of <4% per year. Thus multiple manure applications will have long-term effects on the capacity of the soil to

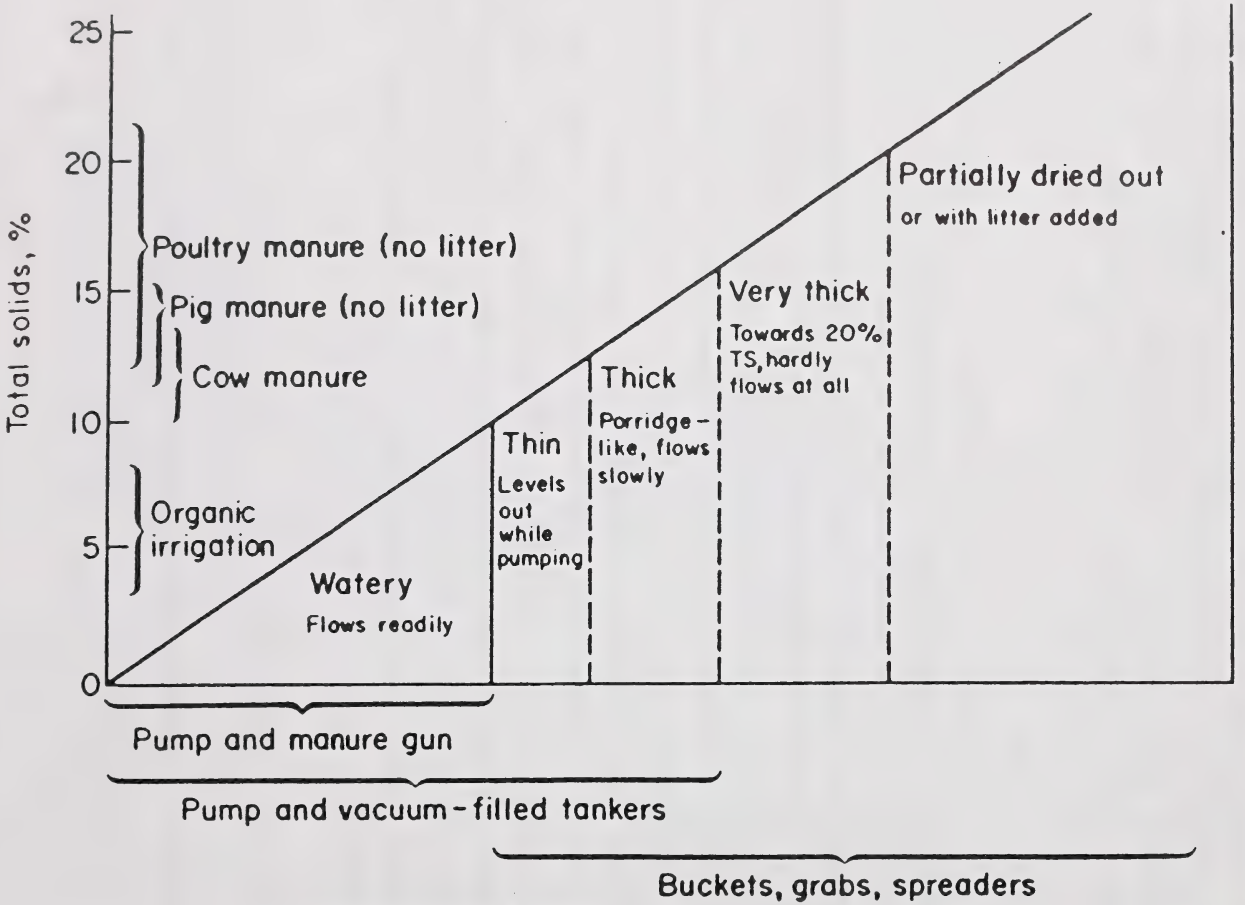

Figure 7. Equipment for handling farm wastes.[a]

[a] Source: After original figure in Schofield (1984).

supply nutrients, and perhaps on the physical properties of the soil as well. Little information is available about the long-term effects of a single application of manure.

The residual effect of manure in supplying nitrogen to plants through ammonification and nitrification has long been recognized (MacLean et al. 1983). Gilbertson et al. (1979, cited by MacLean et al. 1983) presented decay constants estimating the availability of nitrogen to crops from a single application of manure under unknown conditions. They indicate that poultry and swine manures supply more readily available nitrogen in the first year following application than do beef or dairy manures. Beef and dairy manures on the other hand, supply more residual nitrogen in subsequent years. Similar results were reported by McCalla (1974) and Mathers et al. (1972).

How manure is handled can affect the amount of available nitrogen. More nitrogen is available in the first year of application if manure is handled as an anaerobic liquid rather than an aerobic liquid (Brady 1990). A large portion of manure nitrogen is in ammonium form (NH_4-N). If the manure is spread and left on the land surface, much of the NH_4-N is lost through volatilization. In fact, nearly 80% of NH_4-N is lost in the first 5 or 6 days if the manure is not worked in (Wooding 1982). Volatilization is greatest in low CEC soils and in soils that are dry and/or alkaline. Nitrogen that exists in the organic form in manure must be decomposed and mineralized before it is available to the plant as NH_4-N or nitrate-nitrogen (NO_3-N). Manure therefore also provides a slow release source of nitrogen. If manure is worked into the soil far in advance of crop utilization, leaching or denitrification of nitrogen can occur. It is best to apply composted manure just prior to seeding to help prevent nutrient loss.

Little information is available about the longevity in the soil of organic matter from a single application of manure. Stevenson (1986) notes that for each 10 metric tons (dry weight) of manure added to soil, at least one-third and possibly up to one-half will remain behind in a modified form after the first year.

3.1.8 Summary

3.1.8.1 Benefits. Review of the literature suggests that there are a number benefits to the use of manure as a soil amendment:

1. Manure is a major source of nutrients, especially nitrogen, phosphorus, and potassium;

2. Nutrient release from manure is slow after the first year; therefore, manure acts as a slow release fertilizer;
3. Manure is a good, temporary source of organic matter. It increases the soil organic matter content and stimulates biological activity;
4. Manure can improve soil physical properties by increasing porosity, aggregate stability, water infiltration rates, and water holding capacity, and by decreasing bulk density; and
5. Composted manure is odour-, insect-, and weed-free and is easy to handle.

Benefits of manure additions are not permanent. Manure additions do not provide a permanent increase in soil organic matter. The establishment of plants on the soil is important for the long term maintenance of adequate soil organic matter levels. Growing plants will add a continual supply of carbon to the soil.

3.1.8.2 Drawbacks. Some potential concerns to using manure as a soil amendment that need to be considered are:

1. Nitrogen may be lost through by volatilization of NH_4-N, and through runoff, if manure is not incorporated soon after application;
2. Salt accumulates after many years of heavy application and may damage the crops and soil structure;
3. Manure may cause unpleasant odours (especially from NH_3 and H_2S), may attract insects, and may cause dispersal of weed seeds if not composted.
4. Possible heavy metal toxicities may result after many years of heavy application;
5. Manure may be a potential pathogen hazard; and
6. Manure may contaminate surface and ground water supply with nutrients, especially nitrates. Contamination is most likely with excessive rates of application.

3.1.9 Use for Reclamation

Manure has been used to reclaim many types of land disturbances in Alberta and elsewhere (summarized in Table 14).

Table 14. Summary of studies on the use of manure in reclamation.

Reference	Location	Type of Disturbance	Manure Type	Application Rate	Duration	Effect
Rowell and McGill (1977)	Alberta	Oil spill	unknown	100 Mg/ha (wet weight) plus 100 kg/ha N, 50 kg/ha P, and 80 kg/ha K.	Once only application	Significantly increased plant growth where both manure and fertilizer added, compared to manure alone or fertilizer alone.
Hileman (1974)	Arkansas	Brine spill	Poultry manure compost	13 Mg/ha (6 tons/ac)	Once only application	After one year: pH increase from 4.9 to 6.2 P increase from 8 to 81 kg/ha Ca increase from 196 to 459 kg/ha Na decrease from 810 to 56 kg/ha No difference in K, Mg, EC Better moisture retention, better grass survival.
Dormaar et al. (1988)	southern Alberta	Eroded soils	Feedlot manure	30 Mg/ha yearly	21 years	Higher yields than on fertilizer only treatments in drought years. Increased soil organic matter content. Increased N, P and water stable aggregate status of soil.
Solberg et al. (1992)	central Alberta	Eroded soils	Feedlot manure	30 Mg/ha yearly	1 year to date of paper	Lower productivity on manure only treatment compared to fertilizer and replaced topsoil treatments. Higher quality crop on manure treatment compared to fertilizer treatment. Decreased susceptibility to water erosion on manure treatment. None of the treatments including the replaced topsoil treatment restored productivity to undisturbed levels in first year.
Larney et al. (1991)	southern Alberta	Eroded soils	Feedlot manure	50 Mg/ha yearly	1 year to date of paper	Manure was the best treatment to restore productivity of eroded soils.

continued...

Table 14. Concluded.

Reference	Location	Type of Disturbance	Manure Type	Application Rate	Duration	Effect
Bateman and Chanasyk (1992)	central Alberta	Coal mine	Manure	275 Mg/ha, once only application	4 years	Improved distribution of water stable aggregates and aggregate size distribution, exchangeable sodium percentage, and exchangeable cations.
Monenco Limited (1982)	central Alberta	Dry coal ash lagoon	Manure	Topsoil, coal mine spoil, 8 cm horse manure, 5 cm chicken manure, and 8 cm horse and chicken manure treatments plus sulphur.	Unknown	Best plant growth on manure plus sulphur treatment.
Hornick (1988)	Maryland	Sand and gravel spoil	Feedlot manure	40, 80 and 160 Mg/ha	1 year	Better pH, increased nutrient status and water content compared to fertilized control. Decreased soil surface crust strength.
Landsburg and Fedkenheuer (1990)	Northwest Alberta	Soil sterilant affected sites	Well decomposed cow manure	20 cm depth	2 years	Decreased bromacil content.

3.1.9.1 Oil spills. Breakdown or decomposition of oil can be accelerated by adding nutrients, with nitrogen being the nutrient most required (de Jong 1980). Toogood and McGill (1977, cited in de Jong 1980) recommend an initial application of 200 kg nitrogen, 45 kg phosphorus, 85 kg potassium and 25 kg sulphur per hectare. More nitrogen should be added whenever the available $N0_3$-N content of the topsoil drops below 25 ppm. If manure is to be used to supply nutrients, its nutrient status must be tested, so that appropriate amounts of nutrients will be added. Rowell and McGill (1977) found that a manure application plus moderate amounts of fertilizers were sufficient to reclaim an oil spill near Edmonton.

3.1.9.2 Salt affected soil. Salts can be a concern in reclamation, not only after a brine spill, but also in areas where saline and sodic soils have been disturbed.

Soil contaminated by brine water spills can have high salt concentrations, especially Na. Excess Na can have a deleterious effect on soil structure and inhibit the movement of air and water, by breaking down soil aggregation, especially if the soil is leached with rain or snowmelt water. DeJong (1980) recommended an initial application of a Ca amendment or manure (112 Mg/ha (50 tons/acre)) on a brine spill to prevent dispersion of the soil. Further research is needed to determine whether regular additions of manure will effectively reclaim salt affected soils. Although manure maintains favourable soil structure, its salt content is variable. It is therefore recommended that manure be analyzed for salt content before being used as a soil amendment to improve soil physical properties.

In Saskatchewan, applications of manure on undisturbed saline soils at 40 to 60 Mg/ha have been shown to improve crop establishment and crop yields (Henry et al. 1987). Manure increases organic matter content and water holding capacity of soils, adds plant nutrients to soil, and improves soil tilth. Manure additions do not actually rid the soil of salts; rather, improvements in soil physical properties brought about by the manure addition increase movement of water through the soil, resulting in an increased rate of leaching of salts from the soil profile.

Although poultry manure is not commonly used in Alberta, the remediation of a brine spill with composted poultry manure was reported by Hileman (1974) with favourable results. Hileman noted that the composted manure would be more effective than either sewage sludge or commercial fertilizers, because they are high in salts.

3.1.9.3 Eroded soils. A number of studies in Alberta examined the effectiveness of manure in restoring the productivity of artificially eroded soils. These studies are of interest to reclamation because disturbed lands with topsoil lost through mixing or burial have, in a sense, been artificially eroded.

Results of these studies are somewhat varied, but suggest that manure additions can restore productivity and improve soil characteristics over time. In a long term study in southern Alberta, Dormaar et al. (1988) found that both manure and commercial fertilizers restored wheat yields within the first year, regardless of the amount of surface material removed. However, manure was more effective in restoring soil quality, with increases in soil organic matter content, total nitrogen, nitrate-N, available phosphorus, and water stable aggregate status of the soil. This study concluded that in order to restore organic matter characteristics of severely eroded soil, it may be necessary to apply manure annually for many years and to adopt a continuous cropping system.

In a similar study on-going in southern Alberta, Larney et al. (1991) found that manure proved to be the best amendment to restore productivity. In contrast, Solberg et al. (1992) found that after one cropping year, a fertilizer-only treatment proved better than a manure treatment at improving productivity on artificially eroded plots in central Alberta. Crops on the manure treatment were of significantly higher quality, however, as measured by % plump kernels. Application of manure resulted in significant increases in water infiltration and leaf area index, both of which serve to reduce susceptibility to water erosion.

3.1.9.4 Coal mine reclamation. A study at Highvale mine near Edmonton examined the effects of deep ripping reconstructed soils with and without organic amendments (Bateman and Chanasyk 1992). After 4 years, the deep ripping plus manure treatment resulted in improvement in distribution of water stable aggregates and aggregate size distribution, exchangeable sodium percentage and exchangeable cations. The authors concluded that the manure amended soil was more friable, had a lower crusting potential, increased plastic limit, increased aggregation and lower topsoil bulk density than soil that was only deep ripped. Soil quality was found to be improved.

3.1.9.5 Dry coal ash lagoons. Reclamation trials on dry coal ash lagoons at the TransAlta Utilities Wabamum power plant in central Alberta were conducted to determine the best amendments for establishing vegetation (Monenco Limited 1982). Coal ash from power plants has low CEC, high pH, high boron concentrations, low water holding capacity, and low plant nutrients. Various combinations of bulk ameliorants (topsoil, coal mine spoil, and manure) and sulphur were incorporated into the ash. Best results were obtained when manure was used alone, but the manure was also effective when incorporated with minespoil or topsoil. Greatest productivity was with sulphur plus manure treatments.

3.1.9.6 Sand and gravel spoil. Sand and gravel spoil material can be acidic, infertile, coarse textured, and low in organic matter (Hornick 1988). Crops grown on these materials can be subject to high temperatures, and moisture and nutrient stresses. Additions of feedlot manure resulted in more favourable pH conditions for seedling germination and root development, provided essential plant nutrients, and increased water content of the spoil material, compared to fertilized controls. The strength of the soil surface crust was also much higher on the fertilized control compared to the plots with added manure.

3.1.9.7 Soil sterilants. Animal manure has been used to ameliorate soils affected by soil sterilants. Landsburg and Fedkenheuer (1990) report on two NOVA Corporation of Alberta studies that used manure to amend bromacil-affected sites. In a laboratory study, various organic amendments, including a commercially available cow manure, organic fibre, chemically modified peat and activated carbon powder were applied to soils. After one year of incubation, the soils amended with manure showed a slight decrease in biologically available Bromacil, compared to the non-amendment control (Scott 1989, cited in Landsburg and Fedkenheuer 1990). In a field study in northwestern Alberta, bromacil-contaminated soils were treated with 20 cm of well-decomposed cow manure, and with chemical fertilizers. The addition of manure correlated with a decrease in bromacil.

In a field manual for reclaiming soils affected by sterilants (Industrial Vegetation Management Association of Alberta 1985) manure is recommended as the amendment of choice to promote the biological degradation of bromacil and tebuthiuron. An application of 10 to 15 cm of manure is recommended, incorporated to plow depth, along with fertilizer as required by soil analysis. In addition, it is recommended that the area be "capped" with 2 to 3 cm of manure on the surface. Treated soils should be resampled after 4 to 6 weeks to determine the concentration of remaining active ingredient, and to determine soil nutrient levels.

3.1.10 Recommendations for Use in Alberta

When using manure as a soil amendment for reclamation in Alberta, the following is recommended:

1. Test manure for nutrient content and potential problems such as high concentrations of salts, heavy metals, and contaminants, if there is reason to expect a problem;
2. Match manure rates with crop nitrogen requirements because excess nitrogen can be leached. A single application should not exceed maximum rates recommended for Alberta (Table 12);
3. Incorporate manure soon after spreading to prevent odours, and to avoid loss of nutrients through volatilization and water runoff;
4. Manure must be well incorporated into the soil and not left in layers or piles;
5. Do not apply manure to snow, frozen ground, or areas subjected to sudden runoff (i.e., flood plains);
6. Inject liquid manure into the soil to avoid odour and insect problems; and
7. Composted manure is a good choice for reclamation because it is odour- and insect- free, easy to transport and handle, and weed free. If composted manure is not available, non-composted but well-rotted manure is a better choice than fresh manure.

3.2 CROP RESIDUES

Incorporation of crop residues into the soil is a common farming practice on the prairies. Turning under green manures, growing forages with or without other crops in rotation, and incorporating straw are all used to increase and help maintain organic matter and nutrient content in the soil, and to improve soil physical properties. This section will examine the use of crop residues as a soil amendment.

3.2.1 Types

3.2.1.1 Green manures. The practice of green manuring involves incorporating fresh, undecomposed plant material into the soil by plowing under a growing crop. This practice may add organic matter to the soil, increase available nitrogen in the soil, reduce loss of mineral nitrogen through leaching, and concentrate nutrients in surface soil (British Columbia Ministry of Agriculture Field Crops Branch 1978; Russell 1973; Warman 1980).

Both legumes and nonlegumes are grown as green manure crops. Legumes such as clover, alfalfa, peas, vetches, beans, and trefoil supply nitrogen to the soil (British Columbia Ministry of Agriculture Field Crops Branch 1978). Legumes are deep rooted, and draw nutrients from the subsoil; when these crops are turned under a portion of the nutrients are made available to future crops. Annual, biennial, and perennial legumes can be grown. Legumes must be inoculated with the appropriate Rhizobium bacteria prior to seeding to optimize growth and nitrogen fixation.

Annual legumes appear to have some potential as a green manure crop instead of the more common biennial or perennial legumes, especially in the drought prone Brown and Dark Brown Soil Zones of the Canadian Prairies. Annual legumes as green manure crops have been grown in the Peace River region as well (Rice and Olsen 1989). Growth of annual legumes along with snow trapping resulted in considerable nitrogen-fixation without excessive depletion of soil moisture in southern Saskatchewan even in severe drought years (Biederbeck and Carpenter 1986). Perennial legumes, on the other hand, produce little plant matter and fix little nitrogen in the year of establishment or in drought years (Biederbeck 1988a). When grown for more than one year, the deep roots of perennial legumes can deplete soil moisture reserves to the point where yields of succeeding cereal crops are lowered. Problems with biennial legumes stem from the practice of underseeding the legume to a cereal crop. This practice makes it difficult or impossible to use herbicides for weed control, and the legume also competes with the cereal for moisture and nutrients (Biederbeck 1988a). In the second year, excessive depletion of soil moisture reserves by the legume's deep roots can affect succeeding crop yields in dry years.

A relatively new approach in green manuring is the use of perennial or biennial legumes managed as annuals (Biederbeck 1988a). This approach is generally recommended for the Black and Grey Soil Zones where there is adequate soil moisture in most years.

Nonlegumes (such as annual grasses, rye, wheat, and oats) can also be used for green manuring (British Columbia Ministry of Agriculture Field Crops Branch 1978). Often these crops are seeded as a winter cover and then incorporated into the soil the following spring. Growing a mixture of both legumes and nonlegumes provides greater bulk than a pure legume stand and also supplies some nitrogen to the soil (British Columbia Ministry of Agriculture Field Crops Branch 1978).

There are three ways to manage green manure crops (Coleman 1989):

1. Over-winter green manures, which are sown for over-wintering after the cash crop is harvested;
2. Main-crop green manures, which occupy ground during the growing season in place of a cash crop, often as a summerfallow replacement; and
3. Undersow green manures, which are grown along with the market crop.

3.2.1.2 Forages. Forage crops include annual and perennial legumes and grasses. Legumes in a forage mix supply nitrogen to soils provided the legume is properly inoculated with nitrogen-fixing bacteria (Alberta Agriculture 1981). The root systems of grasses are fibrous and therefore act as good soil binders (Alberta Agriculture 1981). Rhizomatous grasses form a thick stand quickly, form a dense firm sod, and are very competitive. Bunch grasses do not form a thick stand; because of the reduced competition they are more suitable for mixtures with legumes. Forage roots can be a source of organic matter. Forages are generally grown for animal feed, either as hay or as pasture.

3.2.1.3 Straw. Straw can be incorporated, crimped, surface applied as a mulch, or left as standing stubble. Straws of most small grains are suitable for use as a soil amendment. Straw helps control erosion and increase soil organic matter. Oilseed crops produce considerably less residue, and the residues are less effective as an amendment.

3.2.2 Chemistry

3.2.2.1 Chemistry of crop residues. Carbon to nitrogen ratios of mature crop residues are higher than those of younger material, with the result that soil N can be immobilized when older plants are turned under (Russell 1973; Warman 1980). Russell (1973) illustrates this with data for rye (Table 15).

Legume crops have two to three times the amount of nitrogen as nonlegumes. Legumes also have lower carbon to nitrogen ratios throughout their life cycles compared to nonlegumes (Figure 8). Straw has a much higher carbon to nitrogen ratio than other kinds of crops. When using straw as an amendment, sufficient nitrogen must be added to reduce carbon to nitrogen ratios to between 20 and 30, to avoid net nitrogen immobilization.

Table 15. The effect of rye maturity on its nitrogen composition and soil nitrogen after decomposition.[a]

Stage of Maturity	N Content of Dry Matter (%)	Soil N mobilized (+) or immobilized (-) (mg)
Plants 25-35 cm high	2.5	+22.2
Just before heads form	1.8	+3.0
Just before flowering	1.0	-7.5
Grain in milk stage	0.24	-8.9

[a] Source: Russell (1973).

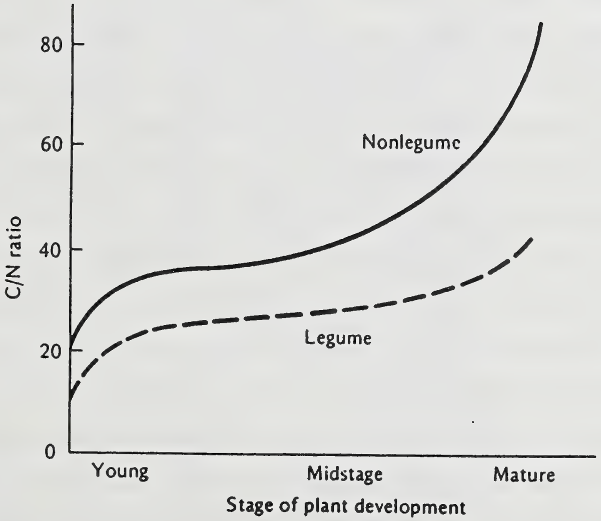

Figure 8. Carbon to nitrogen ratios of legumes and nonlegumes at different stages of development.[a]

[a] Source: Adapted from original table in Brady (1990).

3.2.2.2 Effect of crop residues on soil chemistry. Normally adding crop residues either increases soil organic matter or increases the supply of available nitrogen, but rarely both at the same time (Russell 1973; Warman 1980). Soil organic matter will increase if straw or other mature plant material with a high carbon to nitrogen ratio and resistance to decomposition is added to soil. However, because these materials are usually low in nitrogen, soil mineral nitrogen may become immobilized and unavailable to plants. Available nitrogen increases in soil when material high in nitrogen with a low carbon to nitrogen ratio are added to the soil.

The studies summarized in Table 16 indicate that long-term green manuring can affect the organic matter and nitrogen content of soils. However, these studies, involving both leguminous and non-leguminous green manures, did not find any consistent positive or negative relationships between organic matter accumulation and nitrogen content of the soil. Many factors influence the accumulation of organic matter in soil, including climate, soil and site conditions, type of green manure, and management practices. It is still not known which factors exert the most influence, how they interact, or what the magnitude of the effects will be (MacRae and Mehuys 1985).

In Alberta, Malhi and Nyborg (1990) and Solberg et al. (1991) found that if straw was incorporated, soil had higher organic matter than if straw was removed. Malhi et al. (1992) found that the surface incorporation of commercial urea fertilizers at the rates used could not compensate for soil nitrogen immobilized during straw decomposition. Both nitrogen uptake and yield of the subsequent crop were substantially improved by banding urea fertilizer.

Grass roots add organic matter to the soil. Plant roots are a major source of carbon in grasslands (Herman et al. 1977; Lutwick and Dormaar 1976). Grass root mass of several types of vegetation in various soil zones in Alberta are presented in (Table 17). With most of the grasses, soil organic carbon and root production increased from the Brown to Black Soil Zones. However, in one case where root production in Brown and Black Soil Zones was similar, soil organic carbon content was higher in the Black Soil Zone. The authors concluded that organic matter decomposes to a lower equilibrium in the Brown Soil Zone, than the Black Soil Zone (Lutwick and Dormaar 1976).

Alberta Agriculture (1985) reports that summerfallowing accelerates the loss of organic matter in soil, and that crop rotations with grasses and legumes can help to maintain soil organic matter. Data at the Breton plots in Alberta compared a 2-year wheat-fallow rotation with a 5-year rotation involving wheat, oats, barley, followed by two years of hay. Concentrations of organic matter and soil organic N were higher when forages were part of the rotation (McGill et al. 1986).

Table 16. Effect of long-term green manuring on organic matter and nitrogen content of soils.[a]

Study	Location	Length of Study (yrs)	Green Manure Used	Rotation (X= green manure)	Soil texture	Initial Soil Organic Matter (%)	Initial Soil N (%)	Changes at End of Study	
								Organic Matter	Soil N
Potting Studies									
Prince et al. (1941)	Unknown	40	Vetch	Corn-X-oats-X-wheat-timothy	Loam	3.9	0.197	Decrease	Decrease
De Haan (1977)	Netherlands	10	Legumes and non-legumes	No crop, annual incorporation	Sand Clay	3.9 3.0	0.156 0.224	Increase Increase	Increase Increase
Field Studies									
Poyser et al. (1957)	Manitoba	25	Legumes and non-legumes	X-wheat-corn-wheat	Clay	7.8	0.370	Decrease	Decrease
Mann (1959)	U.K.	18	Legumes and non-legumes	X-kale-potatoes	Sandy loam	1.48	0.090	Increase	Increase
Chater and Gasser (1970) [continuation of Mann (1959)]	U.K.	30	Trefoil	X-barley-potatoes	Sandy loam	1.48	0.090	Same	Increase
			Ryegrass	X-barley	Sandy loam	1.48	0.090	Same	Decrease
Sowden and Atkinson (1968)	Ontario	20	Legumes and non-legumes	Annual application	Clay Sand	2.93 1.20	N.R. N.R.	Decrease Increase	N.R. N.R.

[a] Source: Adapted from original table in MacRae and Mehuys (1985).

[b] Not reported.

Table 17. Grass root production for several crops [a].

Soil Zone	Plant	Organic C % (soil)	Root Production (kg/ha)
Brown	Western wheat grass	1.68	732
	Blue gamma grass	2.48	12 180
	Needle and thread grass	1.32	5 542
Dark Brown	Northern porcupine grass	3.28	6 439
Black	Rough fescue	11.10	12 686

[a] Source: Adapted from original table in Lutwick and Dormaar (1976).

3.2.3 Physical Properties

3.2.3.1 Effect of crop residues on soil physical properties.

3.2.3.1.1 Effect of green manure on soil physical properties. Additions of green manure to soil can result in improved aggregate stability, decreased bulk density, and improved water retention under some conditions.

The effect of green manures on aggregate stability appears to be variable. A literature review by MacRae and Mehuys (1985) indicated that green manures affect aggregate stability, but the effects persist only if continuous additions are made. This review also indicated that effects and effectiveness vary with soil texture and with the type of green manure used (Table 18). Factors such as climate, soil and site conditions, type of green manures, and management practices probably affect long term aggregate stability.

Additions of green manure to soil have generally resulted in decreased bulk density (Table 19) because the added material has lower bulk density than the soil. The decrease in bulk density generally occurs regardless of the type of green manure added. Decreased bulk density may occur immediately after incorporation of the material or may not occur until several years later. The duration of reduced bulk densities was variable.

MacRae and Mehuys (1985) found few studies on green manures in relation to soil moisture properties, but the available literature suggested that water retention may be improved if

Table 18. Effect of green manure on aggregate stability.[a]

Author	Year	Location	Green manure used	soil texture	Effect on aggregate stability
Ram and Zwerman	1960	unknown	variable	variable	variable
Mortensen and Young	1960	Ohio	grass and clovers	silty clay	increase with grass, no effect with clovers
Guttay et al.	1956	Michigan	sweet clover	loam	no effect
Bowren and Wilson	1959	Saskatchewan	sweet clover-wheat-oats rotation	fine sandy loam	increase
Benoit et al.	1962	New Jersey	rye grass	sandy loam	increase over time
Halstead and Sowden	1968	Ontario	rye grass	clay	no effect
Rennie et al.	1954	Saskatchewan	legumes	unknown	increase
Browning and Milam	1944	unknown	unknown	silty clay loam	increase
Chester et al.	1957	unknown	unknown	silt loam	increase
Wisniewski et al.	1958	unknown	unknown	silt loam	increase

[a] Source: Adapted from original table in MacRae and Mehuys (1985).

Table 19. Effect of green manures on soil bulk density.[a]

Author	Year	Location	Green Manure Used	Duration of Study (years)	Soil Texture	Effect on bulk density at end of study
Mortenson and Young	1960	Ohio	grass and clovers	3	silty clay	decrease
Ram and Zwerman	1960	unknown	variable	7	variable	decrease
Benoit et al.	1962	New Jersey	rye grass	6	sandy loam	decrease
Bowren and McNaughton	1967	Saskatchewan	sweetclover-wheat-oats rotation	28	fine sandy loam	no change
Morachan et al.	1972	unknown	alfalfa and cornstalks	13	silty clay loam	decrease
De Haan	1977	unknown (greenhouse study)	variable	10	variable	decrease
Hageman and Shrader	1979	unknown	continuous oats compared to corn-oats-green manure-green manure	20	unknown	no change

[a] Source: Adapted from original table in MacRae and Mehuys (1985).

green manure is added to sandy soils. Ram and Zwerman (1960, cited in MacRae and Mehuys 1985) found increases in soil moisture in treatments with cover crops, when moisture was measured on a gravimetric basis, but not when measured on a volumetric basis. for treatments with cover crops. Morachan et al. (1972, cited in MacRae and Mehuys 1985), found that adding residue increased water retention in a silt loam; however, volumetric determinations were not made.

3.2.3.1.2 Effect of crop roots on soil physical properties. Crop roots, whether from a green manure crop or forage crop can improve soil stability, structure, water infiltration, permeability, and drainage.

Soil stability, including stability of soil aggregates and improvement of soil structure, are affected by root penetration (Goss 1985). As the root penetrates the soil, compression of soil aggregates and reorientation of soil particles occur, resulting in the formation of channels. Such channels may improve drainage and structure of the soil for succeeding crops, because water will be able to percolate deeper and new crop roots will be able to extend further into the soil profile. Plants with strong taproots promote drainage as they provide large holes. Plants with fibrous root systems encourage root growth for succeeding crops. As roots decay, root decomposition products help stabilize soil structure, and contribute to the total humus content of the soil, especially in topsoil (Curl and Truelove 1986; Russell 1973).

Goss (1985) notes that the uptake of water by crop roots results in a series of wetting and drying cycles during the growing season. As the number of these cycles increases, water stability of aggregates also increases (Sillpanää and Weber 1961, cited in Goss 1985). Above an upper limit of cycles, soil stability can decrease (McHenry and Russel 1943, cited in Goss 1985). Goss (1985) suggests that successive drying cycles may improve only those soils with poor structure such as sodic or puddled clays. Shrinkage of clay soils can crack and break up a compacted layer and permit further root exploration. The resulting extension of roots and the formation of root hairs can lead to improved anchorage of the plant. Such root proliferation provides greater capacity for the plant to exploit water and nutrient sources.

3.2.3.1.3 Effect of straw on soil physical properties. Straw spread on the surface of the soil or incorporated into the soil can improve water holding capacity, decrease compaction, and reduce soil erodibility. Greb et al. (1970) found that straw mulches of up to 6.7 Mg/ha (6000 lbs/acre) increased the soil water storage level at the end of a 14-month fallow period. In all cases the fallow efficiency (net soil water stored during fallow period divided by fallow precipitation) increased with additions of wheat straw mulch.

Smika (1983) studied placement of wheat straw mulch (4600 kg/ha) during three 14 month fallow periods (Table 20). Standing stubble was the most effective position for minimizing water loss. During the fallow period, straw position significantly influenced both water storage and storage efficiency. As the amount and height of straw increased, it became more effective in minimizing water loss through evaporation, due to decreased wind velocity near the soil surface and cooler surface temperatures.

Table 20. Fallow period water storage and storage efficiency to 1.8 m, 3 year average.[a]

	Water Storage	
Straw Position	Amount (mm)	Efficiency (%)[b]
flat	137[c]	18.6
3/4 flat, 1/4 standing	234	26.5
1/2 flat, 1/2 standing	272	45.3
bare soil	96	52.9

[a] Source: Adapted from original table in Smika (1983).

[b] Storage efficiency is the water stored divided by precipitation received during storage period X 100.

[c] All values are significantly different at p = 0.01.

Guérif (1979) reviewed straw amendments in relation to soil compaction. He found that bulk density decreased, and plastic limit, liquid limit and plasticity index all increased with additions of straw. He concluded that incorporation of coarse straw fragments reduced compaction due to traffic, because the straw did not allow close packing of the soil aggregates.

The effectiveness of straw mulch for controlling erosion was tested in two studies that used simulated rainstorms. On a silt loam soil with 5% slope in Indiana, Mannering and Meyer (1963) found that mulch rates of 2.24, 4.48 and 8.96 Mg/ha (1, 2, and 4 tons/acre) maintained high infiltration rates and produced no soil erosion. With mulch rates of 0.56 and 1.12 Mg/ha (0.25 and 0.5 tons/acre), 6.72 and 2.24 Mg/ha (3 and 1 tons/acre) of soil were lost respectively, compared with the bare soil treatment (control) in which 26.88 Mg/ha (12 tons/acre) of soil were lost. The authors concluded that surface-applied mulch intercepted precipitation and dissipated its energy, preventing detachment of soil particles and sealing of the soil surface. Thus water was allowed to infiltrate the soil instead of running off. This study suggests that surface-applied wheat straw mulches are effective in controlling soil erosion on gently sloping land. Mulch rates as low as 0.56 and 1.12 Mg/ha (0.25 and 0.5 tons/acre) were able to decrease the amount of soil lost on an annual basis.

In a similar study, wheat straw mulch rates required for erosion control on Indiana loam soils with steeper (15%) slopes were studied by Meyer et al. (1970). Soil losses on the nonmulched soil averaged 62.3 Mg/ha. Mulch rates of 0.56 and 1.12 Mg/ha reduced soil erosion by just over one-third. A mulch rate of 2.24 Mg/ha reduced soil losses by nearly 80%, and rates of 4.48 and 8.96 Mg/ha reduced soil losses by 95%. The authors concluded that much higher rates of straw mulch were required to control soil erosion fully on steep slopes than on more gradual slopes.

3.2.4 Biology of Crop Residues

Crop residues include low and high C:N ratio crops as well as legume and non-legume. The nature of crop determines biology and nutrient balance.

3.2.4.1 Biology of low carbon to nitrogen ratio residues. Green manuring with legume crops increases nitrogen in soil organic matter reserves through nitrogen fixation. Field experiments in western Canada have indicated that only 14% of nitrogen applied as green manure through annual legumes was assimilated by wheat seeded the following spring, whereas 36% of inorganic nitrogen applied as fertilizer in the spring was assimilated (Janzen 1991). Twenty-four percent to 59% of the nitrogen applied as green manure was recovered in the organic matter of the surface soil layer, whereas only 12% to 26% of the inorganic nitrogen was recovered, suggesting that replenishing organic nitrogen reserves is a primary benefit of green manuring. Organic nitrogen reserves are important for sustainability (Janzen 1991). Green manure legumes left on the soil surface may lose appreciable amounts of nitrogen through volatilization (Janzen and McGinn 1991). Incorporation of the green manure into the soil prevents these losses.

3.2.4.2 Biology of high carbon to nitrogen ratio residues. Application of materials like straw with high carbon to nitrogen ratios and low nitrogen content, may result in nitrogen deficiencies because of microbial immobilization of soil available nitrogen during the decomposition process (Norland and Veith 1990; Stevenson 1986). When crop residues with a high carbon to nitrogen ratio are added to the soil, nitrogen fertilizer may be required to overcome the immobilization of available nitrogen (Brady 1990; Russell 1973; Smith and Douglas 1971). The rate of decomposition of the residue can be increased significantly if nitrogen is added, because the nitrogen supply controls the rate of microbial processes. Added nitrogen may allow more of the residue to be converted into microbial tissue, byproducts, and eventually humus (Russell 1973).

3.2.5 Application of Crop Residues to Soil

3.2.5.1 Green manures. It is important that the objective of growing and incorporating green manure crop be clearly established. Incorporated green manure will be beneficial for increasing soil organic matter and soil nitrogen. Non-incorporation is most beneficial for erosion control.

3.2.5.1.1 Selecting suitable species. Ideal green manure crops should (Warman 1980):

1. Be inexpensive to seed;
2. Be easily established;
3. Grow rapidly;
4. Produce abundant succulent tops and roots;
5. Provide good ground cover; and
6. Grow well on poor soil.

In addition, annual legumes considered for use as green manures in the drier southern part of the Canadian Prairies should also meet the following requirements (Biederbeck 1988a):

1. High rate of N_2-fixation and biomass production;
2. High water use efficiency, equal to or better than drought tolerant wheats;
3. High resistance to insect attacks and fungal diseases; and
4. Good ability to compete with broadleaf weeds.

Crops suitable as green manures on the Canadian Prairies include alfalfa, alsike clover, red clover, field peas, fababeans, and sweetclover (Bowren et al. 1987), and chickling vetch and black lentil (Biederbeck 1988a). However, the use of legumes on native prairie should be discussed with the landowner to ensure that their use will not cause problems with species composition. Generally, the optimum time for plowdown is when the legume has reached full bloom. Table 21 gives details about soil preferences, seeding rates, and timing of seeding and turning under for some green manures.

Table 21. Typical green manure crops.[a]

Common Name	Soil Preference	Seeding Rate (kg/ha)	Depth to Cover Seed (cm)	When to Sow	When to Turn Under	Comments
Alfalfa	Loams	16.5	0.7	Spring	Summer or fall	Prefers well-drained soils with high water holding capacity. Highest N fixation
Clover						
Alsike	Heavy loams	6.5	1	Spring or fall	Fall or spring	Less sensitive to soil acidity and poorly drained soils than most clovers
Red	Loams	12.5	1	Spring	Fall	
Field pea	Heavy loams	125	3	Early spring	Summer	
Sweet clover						
Common white	Heavy loams	25	1	Spring	Fall or spring	Quite winter hardy
Yellow	Widely adaptable	25	1	Spring	Fall or spring	Withstands dry conditions better than white sweet clover

[a] Source: Adapted from original table in Warman (1980).

When a green manure is grown, there is no marketable crop. As an alternative to green manure, Izaurralde et al. (1990), examined annual barley and field pea intercropping on a Black Chernozemic soil in Alberta. They found that growing a grain and legume together, increased nitrogen production and nitrogen-fixation efficiency, and increased nitrogen mineralization for subsequent crops.

3.2.5.1.2 Inoculation. Inoculation of leguminous crops involves introducing nitrogen-fixing bacteria into the soil. Bacteria associated with legumes are highly selective and each species will successfully form nodules only on legumes within the same cross-inoculation group. If a mixture of seed is to be grown, then each type of seed must receive its own inoculant (Warman 1980). Inoculant groups common on the Canadian prairies include:

1. Alfalfa group for alfalfa, yellow and white sweet clover;
2. Clover group for common clovers such as alsike, red and white;
3. Pea group for field, garden, sweet pea, vetch, broad bean, lentil; and
4. Bean group for garden and field beans.

Inoculation of legumes is important because the soil may not contain natural populations of the appropriate species of bacteria. According to Biederbeck (1988b), inoculants should be applied with an appropriate adhesive substance. He recommends that rates of inoculant be doubled in dryland areas. Peat-based inoculants are recommended so that seeds are kept separated. This mixture is then added to the seed drill for seeding. Properly inoculated plants show profuse development of nodules and roots and therefore better vigour, growth, and establishment compared to plants that are not inoculated. Inoculation of annual legumes in southern Saskatchewan resulted in a 136% increase in production and a 134% increase in efficiency of water use (Biederbeck 1988a).

Using commercial fertilizers to compensate for N immobilization is not as important with young green manure plants as with older ones, or with straw additions to soil.

3.2.5.1.3 Plowdown. With the growing interest in the use of annual legumes as green manure crops in drought-prone soils, a number of management methods have been investigated, including (Biederbeck 1988a):

1. Incorporation (discing in the topgrowth);
2. Physical desiccation (undercutting to kill roots);
3. Temporary chemical desiccation (spraying low concentrations of 2,4-D);

4. Complete chemical desiccation (spraying high concentrations of herbicides); and
5. Cutting for feed.

In a study over a three year period, Biederbeck (1988a) found that grain production on fields in which legume green manures had been incorporated was similar to production on fallowed land, and was approximately 24% greater than on fields in which green manures had been chemically desiccated. Grain production on fields in which legumes had been grown to maturity was similar to production on nitrogen and phosphorus fertilized stubble wheat plots (averaged 32% lower than production on fallow land). Grain yields were more affected by method of management than by type of legume.

One method to maintain surface cover and trap snow is to desiccate the annual legume crop in mid-summer in order to leave residue standing over the winter. A greenhouse experiment by Janzen and McGinn (1991) indicated that green manure left on the soil surface loses appreciable amounts of nitrogen through volatilization. Incorporation of the green manure material into the soil was shown to prevent such losses, allowing more nitrogen to remain in the soil for future crop use. However, immediate incorporation of green manures reduces its ability to protect the soil surface and trap snow.

3.2.5.1.4 Frequency. Depending on the objective and the crop chosen, green manure could be grown annually or biennially. Unless the crop is grown with a cash crop, there will be no marketable crop in the green manure year.

3.2.5.1.5 Equipment. Green manure crops are seeded using normal farm equipment. The crop is usually incorporated with a disc.

3.2.5.2 Straw. As with green manures, it is critical that the objective for amending with straw be established before determining an application method. If the objective is to control erosion, or to reduce moisture evaporation or improve infiltration, then a surface application or standing stubble may be appropriate. If the objective is to reduce soil compaction, improve soil structure, improve soil permeability, or increase soil organic matter, the straw should be incorporated. Supplementary nitrogen fertilization should be considered in most cases, because straw decomposition will immobilize available nitrogen in the soil.

3.2.5.2.1 Methods. A number of studies have examined different methods of applying straw to soil. In Wyoming, standing stubble from a previous crop increased infiltration and collected more snow compared to straw crimped into the soil (Schuman et al. 1980). After one winter only 47% of the residue remained for the crimped straw treatment while 94% of the stubble residue remained. A laboratory study found that surface application of straw was more effective than incorporated straw in preventing interril soil erosion (McGregor et al. 1988). A greenhouse study, aimed at determining how placement of residue affected decomposition and evaporation on a silty clay loam soil in Texas (Unger and Parker 1968), found that surface-applied straw substantially reduced evaporation, compared to an equal amount of residue mixed into the soil.

3.2.5.2.2 Timing. Fall is probably the best time to apply straw. Straw will reduce erosion over the winter, and immobilize nitrogen to prevent late fall and early spring losses. If applied in the fall, straw will be partially decomposed at spring seeding.

3.2.5.2.3 Rates. Amount of straw to be used and placement of the straw will depend on whether the goal of the amendment is to control erosion or increase soil organic matter. The current interest in no-till farming has generated information on straw management as it relates to erosion control. Straw residue cover in cultivated fields is important to help prevent wind and water erosion. Recommended amounts of residue for summerfallowed fields and fall-worked fields for all soil zones in Alberta are shown in Table 22. These levels assume a partially standing residue. Crop residues are 2.5 times more effective if left standing rather than flat; incorporating straw further decreases its ability to protect against erosion. However, incorporation speeds up decomposition which is an asset in terms of increasing soil humus. More standing residue is recommended on steep slopes, water courses, and knolls. These levels also assume small grain straw; oilseed residues are only 50% as effective (Prairie Farm Rehabilitation Administration 1989).

In a reclamation context, if erosion is likely to occur, immediate measures must be taken. Drifting can usually be controlled if measures are taken before the soil starts to blow. Alberta Agriculture (1985) lists a number of emergency control measures (Table 23). The straw should be applied to the soil surface and lightly disced to anchor it. Another emergency measure involves setting up rows of small rectangular bales, placed 9 to 15 m apart, at right angles to the wind.

Table 22. Straw residue levels required to control erosion in areas with a high susceptibility to wind erosion.[a]

Soil Zone	Summerfallow Fields Residue Required (Mg/ha)	Fall Worked Fields Residue Required (Mg/ha)
Brown	2.2	0.9
Dark Brown	1.8	0.7
Black	1.6	0.6
Gray	1.2	0.5

[a] Source: Adapted from original table in Prairie Farm Rehabilitation Administration (1989).

Table 23. Recommended rates of straw application for erosion control.[a]

Soil Texture	Straw Application Rate
Sands and well worked heavy clays	3.4 to 9 Mg/hectare
Fine sandy loams to silty loams	2.2 to 4.5 Mg/hectare
Clay loams to silty clay loams to clays	1.1 to 3.4 Mg/hectare

[a] Source: Alberta Agriculture (1985).

3.2.5.3 Forages.

3.2.5.3.1 Selection of species. There is a kind and variety of forage for every location and soil type. Ziemkiewickz (1984) lists the grasses and legumes used most extensively for revegetation in North America, along with revegetation parameters ranked on a subjective scale of 1 to 10 (Table 24). In Alberta, five species do particularly well: red fescue, crested wheatgrass, Canada bluegrass, alfalfa and alsike clover.

3.2.5.3.2 Seeding rates. Seeding rates recommended by Alberta Agriculture for forage crops and mixtures adapted to Alberta conditions are shown in Table 25 (Alberta Agriculture 1992). It is recommended that "Varieties of Perennial Hay and Pasture Crops for Alberta" Alberta Agriculture (1992), be consulted for further information.

Seeding should be done in a firm clean seedbed or clean undisturbed grain stubble. Companion crops are usually not recommended unless soil is eroding or subject to high rainfall (Alberta Agriculture 1981). Legumes should be properly inoculated with an inoculum specific to the legume grown. Seed when moisture conditions are favourable. For example, in the southern prairies, seed in the spring to take advantage of the spring moisture. Late fall seeding is recommended in areas subject to spring flooding and in peat areas that are wet until after summer.

3.2.5.3.3 Fertilizer. When properly inoculated, legumes need little or no additional nitrogen. However, they do need relatively large amounts of phosphorus, potassium, and sulphur (Alberta Agriculture 1981). Most Alberta soils have adequate potassium, but some soils in the Black and Gray Soil Zones are sulphur deficient. Grasses require large amounts of nitrogen and smaller amounts of phosphorus, potassium, and sulphur. In a grass-legume mixture, it is difficult to obtain an ideal fertilizer combination. Fertilizer requirements for grasses, legumes, and mixtures in Alberta are shown in Table 26.

Generally, in wildland areas, both nitrogen and phosphorous, but not potassium, are in short supply. Ziemkiewickz (1984) suggested that the first addition of fertilizer should provide 50 to 75 kg/ha of nitrogen and phosphorous. After that, only half this rate should be added if the cover crop starts yellowing or dying off in the middle of the first two years. Excessive fertilization is not encouraged in order to allow the legumes to develop and to fix nitrogen. Apply fertilizer in the spring.

Table 24. Grass and legume species revegetation parameters and ratings.[a,b]

	Drought Tolerance	Nutrient Deficiency Tolerance	Grazing Resistance	Fire Resistance	High Elevation Tolerance	Flooding Tolerance	Acid Tolerance	Salt Tolerance	Erosion Control
Grasses									
Canada Bluegrass	9	1	10	10	8	1	8	8	9
Crested Wheatgrass	10	1	10	9	2	1	1	9	8
Intermediate Wheatgrass	8	1	9	1	4	1	1	7	8
Meadow Foxtail	5	1	7	2	10	9	8	1	8
Orchardgrass	4	1	2	2	9	1	6	1	8
Perennial Ryegrass	5	1	6	5	2	1	5	1	8
Red Fescue	8	1	8	5	10	1	10	3	10
Red Top	1	1	5	5	10	8	9	1	8
Reed Canarygrass	3	1	7	1	1	10	5	8	8
Sheep Fescue	8	1	5	8	10	1	6	1	5
Slender Wheatgrass	8	1	7	2	6	1	4	7	8
Smooth Brome	8	1	7	1	5	1	10	4	9
Tall Wheatgrass	8	1	10	1	2	7	1	10	8
Timothy	5	1	9	1	10	3	6	1	4
Western Wheatgrass	9	1	8	2	2	1	1	10	8

continued...

Table 24. Concluded.

	Drought Tolerance	Nutrient Deficiency Tolerance	Grazing Resistance	Fire Resistance	High Elevation Tolerance	Flooding Tolerance	Acid Tolerance	Salt Tolerance	Erosion Control
Legumes									
Alfalfa	8	10	4	5	5	1	1	8	8
Alsike Clover	5	10	6	8	10	1	7	1	8
Birdsfoot Trefoil	5	10	4	7	3	1	6	1	5
Cicer Milkvetch	7	10	7	6	7	1	2	6	3
Red Clover	1	10	3	8	3	1	3	1	8
Sainfoin	8	10	4	5	3	1	1	7	5
Sweetclover	9	10	10	1	1	1	1	10	1
White Clover	1	10	6	8	8	2	3	1	8

[a] Source: Ziemkiewicz (1984).

[b] To use this table, identify critical site parameters, add up rating values, and divide the total by the number of parameters for an average rating. Select the three highest ranked grass and two highest ranked legumes.

Table 25. Recommended seeding rates for adapted crops and mixtures commonly used in Alberta.[a]

Area and Row Spacing (cm)	Crops	Approximate Seeding Rate[b] (kg/ha)	
		Hay	Pasture
Brown Soil Zone[c]			
45 to 60	Alfalfa	4	NR[f]
30 to 45	Alfalfa + smooth bromegrass (moister areas)	2+7	1 to 2+7
45 to 60	Alfalfa + crested wheatgrass	2+4	1 to 2+4
30 to 45	Alfalfa + intermediate or pubescent wheatgrass (moister areas)	2+8	1 to 2 + 8
60 to 90	Alfalfa + Altai wild rye	NR	1 to 2 + 4
45 to 60	Alfalfa + Russian wild rye	NR	1 to 2 + 3
Dark Brown Soil Zone[c,d]			
30 to 45	Alfalfa	5	NR
15 to 30	Sweet clover	8	NR
30 to 45	Alfalfa + smooth bromegrass	2+7	1 to 2 + 7
30 to 45	Alfalfa + crested wheatgrass	2+5	1 to 2 + 5
30 to 45	Alfalfa + intermediate or pubescent wheatgrass	2+8	1 to 2 + 8
45 to 60	Alfalfa + Altai wild rye	NR	1 to 2 + 6
30 to 45	Alfalfa + Russian wild rye	NR	1 to 2 + 5

continued...

Table 25. Continued.

Area and Row Spacing (cm)	Crops	Approximate Seeding Rate[b] (kg/ha)	
		Hay	Pasture
Black Soil Zone[c]			
15 to 20	Alfalfa	8	NR
15 to 20	Sweet clover	9	NR
15 to 20	Bird's-foot trefoil (moister areas)	6	6
15 to 20	Alfalfa + meadow bromegrass	NR	1 to 3 + 10
15 to 20	Alfalfa + smooth bromegrass	5+6	1 to 3 + 8
15 to 20	Alfalfa + smooth bromegrass + creeping red fescue	NR	2 to 3 + 6 + 2
15 to 20	Alfalfa + smooth bromegrass + timothy (moister areas)	5 + 6 + 2	2 to 3 + 7 + 2
15 to 20	Alfalfa + orchard grass	NR	2 to 3 + 6
15 to 20	Alfalfa + timothy	5 + 2	2 to 3 + 3
15 to 20	Alfalfa + crested wheatgrass	4 + 5	1 to 3 + 7
15 to 20	Alfalfa + intermediate wheatgrass	5 + 7	1 to 3 + 9
15 to 20	Alsike clover + creeping red fescue or meadow foxtail (moist and flooded areas)	4 + 4	2 + 5
15 to 20	Creeping red fescue or meadow foxtail (moist and flooded areas)	5	5

continued...

Table 25. Continued.

Area and Row Spacing (cm)	Crops	Approximate Seeding Rate[b] (kg/ha)	
		Hay	Pasture
Gray Luvisol Soil Zone[e]			
15 to 20	Alfalfa	8	NR
15 to 20	Sweet clover	9	NR
15 to 20	Bird's-foot trefoil (moister areas)	6	6
15 to 20	Alfalfa + meadow bromegrass	NR	1 to 3 + 10
15 to 20	Alfalfa + smooth bromegrass	5 + 6	1 to 3 + 8
15 to 20	Alfalfa + smooth bromegrass + creeping red fescue	NR	2 to 3 + 6 + 2
15 to 20	Alfalfa + creeping red fescue + intermediate wheatgrass	NR	2 to 3 + 6 + 2
15 to 20	Alfalfa + red clover + timothy	2 + 3 + 4	NR
15 to 20	Alfalfa + timothy	5 + 3	2 to 3 + 3
15 to 20	Alfalfa + intermediate wheatgrass	5 + 7	1 to 3 + 9
15 to 20	Alsike clover + reed canary grass (moist and flooded areas)	4 + 4	2 + 6
15 to 20	Alsike clover + creeping red fescue + timothy (moist and flooded areas)	2 + 3 + 3	2 + 3 + 2
15 to 20	Alsike clover + creeping red fescue or meadow foxtail (moist and flooded areas)	4 + 4	2 + 5
15 to 20	Alsike clover + timothy	4 + 4	NR
15 to 20	Creeping or meadow foxtail (moist or flooded areas)	5	5

continued...

Table 25. Concluded.

Area and Row Spacing (cm)	Crops	Approximate Seeding Rate[b] (kg/ha)	
		Hay	Pasture
Irrigation			
15 to 20	Alfalfa	10	NR
15 to 20	Sainfoin	35	35
15 to 20	Alfalfa + Kentucky bluegrass	NR	2 + 10
15 to 20	Alfalfa + meadow or smooth bromegrass	5 + 8	2 + 10
15 to 20	Alfalfa + orchard grass	4 + 8	2 + 8
15 to 20	Alfalfa + intermediate or pubescent wheatgrass	5 + 12	2 + 12
15 to 20	White clover + meadow bromegrass + orchard grass	NR	2 + 8 + 6

[a] Source: Alberta Agriculture (1992).

[b] Increase seeding rate by about one-half if broadcasting the seed and harrowing it into soil.

[c] Cicer milk-vetch at 5 to 6 kg/ha can be substituted for alfalfa in pasture mixtures.

[d] Sainfoin at 10 to 15 kg/ha can be substituted for alfalfa in pasture mixtures.

[e] Mixtures containing sweet-clover are useful on poorly structured Gray Luvisol soils where crusting and compaction occur.

[f] NR - not recommended.

Table 26. Fertilizer recommendations for grass-legume mixtures (kg/ha).[a]

Soil Zone	Element	Grasses[b]	Mixtures		Legume[c]
			20 to 40 % legume	40 to 60 % legume	
Brown		NR[d]	NR	NR	NR
Irrigation	N	56 to 112[e]	45 to 78[e]	34 to 56	0 to 11
	P_2O_5	0	56	56	34 to 67
Dark Brown	N	45 to 90	34 to 67	11 to 45	0 to 11
	P_2O_5	0 to 17	0 to 22	0 to 34	0 to 34
Black and Gray	N	56 to 112	45 to 90	11 to 45	0 to 11
	P_2O_5	0 to 34	0 to 34	0 to 45	0 to 56
	S	0 to 11	0 to 22	0 to 22	0 to 22

[a] Source: Adapted from original table in Alberta Agriculture (1981).

[b] Grasses or mixtures with less than 20% legume.

[c] Legumes or mixtures with more than 60% legume.

[d] N/R - None recommended.

[e] To maintain peak production, follow with another 56 kg N/ha in mid-June and again in mid-July.

3.2.5.3.4 Application methods. Ziemkiewickz (1984) provides a number of suggestions for forage seeding. Cover seed with soil or mulch. Cultivate or harrow after seeding. Seed can be broadcast at rates of 50 kg/ha. When using a broadcasting method, apply seed and fertilizer together in the spring. Harrow within a few days. Seeding with seed drills requires a smooth seed bed. Seed and machine use is minimized with the use of a seed drill. Rates for drill seeding may be halved.

Hydroseeding is a method of applying seed and fertilizer (Ziemkiewickz 1984) that is generally used for steep slopes and is very expensive. Mulches can be applied, especially if erosion is considered a hazard.

3.2.6 Costs

Costs vary depending on the type of residue amendment required. A potential cost in using a green manure crop is that it replaces a potentially marketable crop. However, if green manure is used as a summerfallow substitute, this disadvantage disappears. Forage crops will improve soil conditions in the long term only. They become economically feasible if there is a readily available market for forages, or if the landowner raises cattle. Straw has in the past been considered a waste product, and in some areas may be readily available at low cost. In areas where conservation tillage is practised, straw may be difficult to find. In northern areas with no nearby arable agricultural land, hauling costs could be very high.

3.2.7 Longevity of Effect

The longevity of effect of any crop residue applied to the soil will be a function of its carbon to nitrogen ratio, chemical composition, method of placement, type of plant material, and environmental factors such as soil moisture, temperature, and availability of nutrients such as nitrogen and phosphorus. Generally, the higher the carbon to nitrogen ratio, the more resistant to decomposition the material will be, unless supplementary nitrogen and possibly phosphorus are added. Standing straw stubble or surface-mulched straw or other residue will decompose more slowly than incorporated straw. Rate of decomposition increases with warmer temperatures and good soil moisture. Waterlogging can slow decomposition.

If soil organic matter content is to remain constant additions must equal losses. For example, unless a single application of residue amendment sufficiently stimulates plant production so that organic matter is continually being added to the soil through increased plant yields, organic matter content will gradually decrease. Soil management after the initial amendment addition will be critical to sustaining organic matter content in the long term.

3.2.8 Summary

3.2.8.1 General benefits.

1. Soil organic matter content can be increased;
2. Soil physical properties, including infiltration rate, water holding capacity, aggregation and bulk density can be improved; and
3. Soil erosion by both wind and water can be controlled.

Benefits of a single crop residue addition are not permanent. Turning under green manures, growing forages with and without other crops in rotation, and incorporating straw ahould be repeated at regular intervals.

3.2.8.1.1 Additional benefits of green manure. From Biederbeck (1988a), Warman (1980):

1. Increased available nitrogen;
2. Improved microbiological activity and nutrient cycling;
3. Reduced leaching of nutrients; and
4. Increased yields of succeeding crops.

3.2.8.1.2 Benefits of straw. The use of straw as a mulch provides the following benefits (Brown et al. 1980; Norland and Veith 1990):

1. Shading and moderation of temperature extremes;
2. Conservation of soil moisture and decreased evaporation;
3. Protection of soil from baking by sun, and from compaction and crusting by rain.

The use of standing straw from annual crops provides (Brown et al. 1980):

1. Economic return from a crop which can offset revegetation costs,
2. Protection of soil and perennial seedlings from wind erosion and excessive drying; and
3. Trapping of snow if stubble is left standing.

3.2.8.1.3 Benefits of forages. In addition to the benefits of using any crop residue, the use of a forage crop provides the following benefits (Serecon Management Consulting Inc. 1992):

1. Increased interception of precipitation;
2. Increased trapping of snow;
3. Increased nutrient cycling; and
4. Break-up of soil compaction.

3.2.8.2 Drawbacks.

3.2.8.2.1 Drawbacks of green manures. Disadvantages or problems that can occur with the use of green manures include (Warman 1980):

1. If legumes are not included in the green manure crop, high carbon to nitrogen ratio may result in depressed nitrogen uptake by the succeeding crop;
2. Unless the green manure crop is chosen carefully, it can deplete soil moisture in areas with low rainfall, to the point where succeeding crops may suffer from drought; and
3. If legumes are used, seed is expensive, difficult to establish, and the crop is valuable as animal feed, so that there may be some reluctance to turn the crop under.

3.2.8.2.2 Drawbacks of straw. Some problems that can occur with the use of mulches include (Brown et al. 1980):

1. Difficulty of broad uniform application;
2. Problems with harbouring weed seeds; and
3. Difficulty of keeping the mulch in place.

Disadvantages with the use of straw from annual crops include (Brown et al. 1980):

1. Competition with perennial seedlings;
2. Persistence of plants if seeds are not harvested; and
3. A succeeding cover crop may be necessary to prevent erosion in winter months.

3.2.8.2.3 Drawbacks of forages. There are few drawbacks to growing forages if they are appropriate for the location.

3.2.9 Use for Reclamation

Forage production is a common end use of many reclaimed areas. However, the effects of the forage crop on soil properties after reclamation and initial revegetation are not well documented. Green manures are rarely used for reclamation.

Straw is often used as an erosion control measure on erosion-prone reclamation sites. In a reclamation context, the use of straw to increase soil organic matter content and improve soil physical properties is less common. However, rototilling straw into the upper subsoil before topsoil is replaced, is sometimes used on wellsites in Alberta to break up compaction and improve water infiltration. Straw has also been used as an amendment on wellsites to increase the carbon to nitrogen ratio of the soil after a heavy application of calcium nitrate to brine spills. Application of straw may help prevent excessive leaching of nitrogen, and possible contamination of groundwater (D. Headdon, Western Oilfield Environmental Services, Calgary, Alberta, personal communication, 1992). Results from the use of straw on wellsites have not been adequately documented.

Olsen and Jones (1989) reported that incorporation of crop residue and other organic amendments into reconstructed stripmine spoil may provide an alternative to topsoil replacement. Treatments included:

1. Nonamended spoil;
2. Cattle manure at rates of 50, 100, 200 Mg/ha dry weight;
3. Green manure crop of cereal rye and hairy vetch planted annually and incorporated each spring;
4. Sod-building forage crop of tall fescue, timothy, sweet clover, and oats; and
5. Replacement of 30 cm of topsoil.

Treatments were applied to four different soil materials (B horizon, loess, glacial till, and a belt mix excluding the A horizon), at a mine site in Illinois for a 2 year period. Bulk densities were lower in the second year after incorporation of the organic amendments compared to the unamended spoil, but not in the first year when wet soil conditions prevailed. All organic amendments increased the organic matter contents of the soil materials after 2 years. However, only the manure treatments were able to restore corn yields to levels equivalent to the replaced topsoil treatment.

3.2.10 Recommendations for Use in Alberta

It is important to establish the exact objective for using the crop residue amendment, before choosing the type of residue to use for reclamation. Residues can be useful for wind and water erosion control, increasing soil organic matter and nitrogen content, and improving the physical properties of the soil. Table 27 outlines recommended reclamation uses for various crop residues, derived from information presented in this discussion.

Table 27. Recommended crop residues for reclamation uses.

Residue	Soil Erosion Control	Increase Soil Organic Matter	Increase Soil N	Improve Soil Physical Properties	Comments
Green Manures					
Legumes and legume mixtures	Some control once established	Increase with long term application.	Yes, especially if young plants turned under.	Yes	If mature plant material is turned under, supplemental N may be needed.
Non-legumes	Some control once established	Increase with long term application.	Possibly some if young plants turned under	Yes	Will require supplemental N
Straw					
Standing stubble	Good control for gentle slopes.	Some increase, but slow decomposition.	No	Improves snow trapping and water infiltration. Moderates soil temperatures.	Any addition of straw to soil will immobilize soil N. Subsequent crops will suffer if supplemental N is not added.
Surface mulch	Best for control on steeper slopes. Rates depend on steepness.	Some increase, but slow decomposition.	No	Improves water infiltration. Moderates soil temperatures.	Straw is the longest lasting of the crop residue amendments. Rate of decomposition depends on availability of soil or fertilizer N.
Crimped	Some control	Some increase, quicker decomposition.	No	Improves infiltration, water holding capacity. May decrease bulk density.	
Incorporated	Some control	Best application method for soil organic matter buildup. Needs supplemental N.	No	Best method of application for improving soil physical properties.	
Forages	Good control once established.	Increase with long term use.	Yes, if legume or legume mixture used.	Improves snow trapping, water infiltration and water holding capacity. Decreases bulk density and relieves compaction. Many improvements are over the long term only.	Grass-legume mixtures are most appropriate for most reclamation applications.

3.3 PEAT

3.3.1 Types

Many terms are used to define peat. Agriculture Canada defines peat as "unconsolidated soil material consisting largely of undecomposed, or only slightly decomposed, organic matter" (Canada Department of Agriculture 1976). Other definitions of peat are often related to classification systems, botanical origin or degree of decomposition. For example, fibre content was used as the basis for the classification of peat proposed by Farnham and Finney (1965, cited in Logan 1978). Fibre content was the portion by weight of fibre larger than 0.1 mm. Peat classes included Sapric, with less than 1/3 fibre content (most decomposed); Hemic, with 1/3 to 2/3 fibre content; and Fibric, with over 2/3 fibre content (relatively undecomposed). Farnham (1968, cited in Logan 1978) also proposed a commercial standard for peat that was mixed and sold for horticultural uses. Criteria were based on botanical origin and degree of decomposition. The four classes of peat under this system were sphagnum moss peat, other moss peat, reed-sedge peat and other peat.

Most peat materials originate from organic soils. Details of the genesis of organic soils are described by Valentine et al. (1987). In Canada, organic soils are divided into three great groups: Fibrisols, Mesisols, and Humisols (Agriculture Canada Expert Committee on Soil Survey 1987). These groups are differentiated by the amount and durability of fibre. They are made up mainly of mosses, sedges and other hydrophytic vegetation. Organic soils are generally saturated with water for most of the year, have greater than 30% organic matter (17% organic carbon), and are over 40 cm deep. Fibrisols are relatively undecomposed, Mesisols are intermediate, and Humisols are the most decomposed.

Durability of fibre, as measured by destruction on rubbing through a 100 mesh sieve (0.15 mm) is a relative measure of the state of decomposition of peat. Fibric, mesic and humic peat materials have rubbed fibre contents as follows (Agriculture Canada Expert Committee on Soil Survey 1987):

1. Fibric peat > 40% fibre remaining by volume;
2. Mesic peat 10% to 40% fibre remaining by volume; and
3. Humic peat < 10% fibre remaining by volume.

Organic soils that are so markedly decomposed that the original plant parts cannot be identified are sometimes called muck soils (Brady 1990). Muskeg is a term used loosely to refer to organic soil materials of various types originating in northern Canadian bogs.

Peat soils in Alberta can be simply divided into sedge peats and moss peats. Many are a mixture of the two (Alberta Agriculture 1982). Moss peats are most commonly derived from the moss genus *Sphagnum* or other moisture-loving plants, whereas sedge peats are derived mainly from sedges and are usually formed in depressions where outflow of water is restricted. In northern Alberta, organic soils consist of fine-textured fibrous sedge peat or coarse-textured *Sphagnum* moss peat associated with bogs and muskeg (Lindsay et al. 1962, cited in Logan 1978).

3.3.2 Sources

According to the Canadian Sphagnum Peat Moss Association, about 7 000 000 m^3 of peat is harvested annually in Canada. No figures are available for total annual production in Alberta (G. Hood, Canadian Sphagnum Peat Moss Association, St. Albert, Alberta, telephone conversation October 21, 1992), but peat materials are widely available in Alberta. A number of companies harvest and bag peat for horticultural use. One operator in the Edmonton area harvests and bags peat in 0.11 m^3 bags (4 ft^3), yielding about 2800 m^3 (100 000 ft^3) per year. Peat is also available from the same company by the truck load, but most is sold for horticultural use by the bag (D. Turner, Lakeland Peat Moss, Edmonton, Alberta, telephone conversation October 22, 1992). Most peat is harvested in the northern half of the province, and materials can be expected to be more widely available there.

3.3.3 Chemistry

3.3.3.1 Chemistry of peat.

3.3.3.1.1 Organic matter. Organic matter composition of peat is dependent on the type of plant residue from which peat is formed and on the degree of decomposition of the residues. Plant residues consist of lignin, cellulose, hemicellulose, nitrogenous compounds, fats, waxes, resins and water-soluble constituents (Puustjarvi and Robertson 1975). Some of these compounds, such as starches, fats and sugars, can be readily assimilated by microorganisms and used as a source of energy.

Others, such as lignin, are more resistant to alteration and therefore accumulate during decomposition.

In Alberta, organic carbon % for four peat samples collected by Logan (1978) in the Fort McMurray, Alberta area ranged from 37.6% to 45.2% (66% to 80% organic matter content). Organic matter % of commercial peat in Alberta ranges from 90% to 98% (Canadian Sphagnum Peatmoss Association, St. Albert, Alberta, 1989 unpublished data).

3.3.3.1.2 Carbon to nitrogen ratio. Carbon to nitrogen ratios ranging from 17 to 74 have been reported (Logan 1978). Canadian Sphagnum Peat Moss Association (St. Albert, Alberta, 1989 unpublished data) reports that the carbon to nitrogen ratio range for commercial peats is normally 50 to 85. Carbon to nitrogen ratios for four peat samples collected in the Fort McMurray area ranged from 23 to 51 (Logan 1978). The highest carbon to nitrogen ratio was for a fibric (acid) peat and the lowest was for a mesic (stockpiled) peat.

3.3.3.1.3 pH. Generally, for a given percentage base saturation, peat soils are somewhat more acid than mineral soils (Brady 1990). pH varies both within and between different peat deposits, and tends to increase at greater depth (Walker 1934, cited in Logan 1978).

pH of Alberta peat soils ranges from acid (pH 3.5) to slightly alkaline (pH 7.5) (Alberta Agriculture 1982). pH of a fibric (acid) peat was 3.8, a mesic peat was 6.3, fibric peat was 5.8, and a mesic stockpiled peat was 6.0 for samples collected in the Fort McMurray area (Logan 1978). The Canadian Sphagnum Peat Moss Association (St. Albert, Alberta, 1989 unpublished data) stated that pH for commercial peat ranges from 3.8 to 5.5.

3.3.3.1.4 Nutrient content. Nitrogen and phosphorous are generally present in peat in organic forms that are slowly available to plants (Puustjarvi and Robertson 1975). Organic soils contain only low amounts of available micronutrients. Deficiencies of copper, zinc, manganese, and boron are common in crops grown entirely on peat (Brady 1990). Puustjarvi and Robertson (1975) report that nitrogen content ranges from 0.8% to 2.5% in different peats. Lowest nitrogen concentrations were found in sphagnum peat; highest concentrations were found in sedge peat. Similar results from a number of studies were reported by Logan (1978). Walker (1934, cited in Logan 1978) found nitrogen content was highest in the more decomposed layers.

Canadian Sphagnum Peat Moss Association (St. Albert, Alberta, 1989 unpublished data) supplied ranges for some plant nutrients in commercial peats in Alberta (Table 28).

Table 28. Ranges of plant nutrients in commercial peats in Alberta.[a]

Nutrient	Range
Total N	0.8% to 1.0%
PO_4-P	up to 100 ppm
K	250 to 350 ppm
Ca	6000 to 8000 ppm
Mg	1000 to 2000 ppm
Zn	trace
Mn	trace
Fe	trace
B	0.15 to 0.5 ppm

[a] Source: Canadian Sphagnum Peat Moss Association, St. Albert, Alberta, 1989 (unpublished laboratory results).

3.3.3.1.5 Cation exchange capacity (CEC). Total CEC for four peat samples collected in the Fort McMurray area ranged from 156 me/100g for a poorly decomposed fibric peat, to 263 me/100g for a more completely decomposed mesic peat (Logan 1978). The higher CEC of the mesic peat suggests a greater buffering capacity.

3.3.3.1.6 Electrical conductivity (EC). Electrical conductivity of peats tends to be very low. The Canadian Sphagnum Peat Moss Association (St. Albert, Alberta, 1989 unpublished data) indicated that EC is generally less than 1 dS/m in Alberta.

3.3.3.2 Effect of peat additions on soil chemistry. Peat additions to soil can be expected to modestly increase nutrients available to plants during slow decay. Brady (1990) notes that despite relatively high carbon to nitrogen ratios, organic soils often exhibit substantial mineralization and nitrification, so that less soil nitrogen is immobilized than would be expected. The "effective" carbon to nitrogen ratio of peat materials may be lower than the "apparent" carbon to nitrogen ratio, because a large proportion of the carbon may be unavailable to microorganisms.

The acidic nature of most peats can be expected to lower the pH of soil to which it is added. Additions of lime may be necessary if peat is added to neutral or acidic soils, or if additions are large or frequent. Peat additions to soils with low CEC (i.e., sand) increase the buffering capacity or the ability of soil to resist a change in pH due to fertilization (Lucas and Rieke 1968, cited in Logan 1978). The increase in CEC of soil which has had peat additions will also increase the soil's ability to retain plant nutrients.

3.3.4 Physical Properties

3.3.4.1 Physical properties of peat.

3.3.4.1.1 Degree of decomposition. Many physical characteristics of peat are determined by degree of decomposition of organic residues (Puustjarvi and Robertson 1975). A widely-used scale to determine degree of decomposition in fresh sphagnum peat was devised by von Post (Table 29). For practical purposes, three general categories of peat are recognized (Puustjarvi and Robertson 1975):

1. Undecomposed (von Post classes H1-H3);
2. Partly decomposed (von Post classes H3-H6); and
3. Highly decomposed (von Post classes H6-H10).

Laboratory based methods to determine degree of decomposition are more time consuming (Puustjarvi and Robertson 1975). These include:

1. Microscopic examination of plant remains;
2. Proportion of organic residues insoluble in 72% sulphuric acid; and
3. Colorimetric tests following extraction of peat with a base.

3.3.4.1.2 Particle-size distribution. As peat decomposes, particle size of the material decreases. As particle size decreases, water holding capacity increases and air capacity decreases (Table 30; Puustjarvi 1968, cited in Logan 1978). This occurs even though total porosity is unchanged, because well-decomposed material has a larger proportion of small pores, which retain water better than larger pores.

Table 29. von Post scale to assess the degree of decomposition of fresh peat.[a]

Degree of decomposition	Nature of water expressed on squeezing	Proportion of peat extruded between fingers	Nature of plant residues	Description
H1	Clear, colourless	None	Unaltered, fibrous, elastic	Undecomposed
H2	Almost clear, yellow-brown	None	Almost unaltered	Almost undecomposed
H3	Slightly turbid, brown	None	Most remains easily identifiable	Very slightly decomposed
H4	Turbid, brown	None	Most remains identifiable	Slightly decomposed
H5	Strongly turbid, contains a little peat in suspension	Very little	Bulk of remains unidentifiable	Moderately well decomposed
H6	Muddy, much peat in suspension	One third	Relatively few remains identifiable	Strongly decomposed
H7	Strongly muddy	One half	Only resistant roots, fibres and bark, etc., identifiable	Very strongly decomposed
H8	Thick mud, little free water	Two thirds	Practically no identifiable remains	Almost completely decomposed
H9	No free water	Almost all	Completely amorphous	Completely decomposed
H10	No free water	All		

[a] Source: Puustjarvi and Robertson (1975).

Table 30. Influence of peat particle-size on several physical properties.[a]

Particle-size fraction (mm)	Weight per volume (g/l)	Pore volume (%)	Water capacity (%)	Air capacity (%)
Less than 1	62	96	83	12
1 to 2	52	96	70	27
2 to 4	56	96	64	32
4 to 8	58	96	60	36
8 to 20	57	96	58	38

[a] Source: Puustjarvi (1968, reproduced in Logan 1978).

3.3.4.1.3 Porosity and pore-size distribution. In peat, total pore volumes generally range from 85% to 98%, compared with mineral soils in which total pore volumes of 50% to 70% are more common (Puustjarvi and Robertson 1975). Percentages by volume of capillary or micropores (<0.03 mm) and non-capillary or macropores (>0.03 mm) for different types of peat are shown in Table 31. Capillary water cannot be removed from capillary pores in peat by the force of gravity whereas water in non-capillary pores can be removed by force of gravity. Over 70% of capillary water is normally available to plants (Puustjarvi and Robertson 1975).

Table 31. Percentage by volume of micro- and macropores in different types of peat.[a]

Peat type	Micropores < 0.03 mm	Macropores > 0.03 mm
Coarse sphagnum moss peat	18	78
Medium-coarse sphagnum moss peat	29	66
Fine, dark sphagnum moss peat	43	50
Black peat	50	39

[a] Source: Puustjarvi and Robertson (1975).

3.3.4.1.4 Bulk density. As particle size becomes smaller, weight per unit volume (bulk density) increases. Therefore, fibre content and bulk density are inversely related. However, bulk density of peat also varies with degree of compactness and nature of colloidal particles (Puustjarvi 1968, cited in Logan 1978). Logan (1978) found from various studies that bulk densities of peat ranged from 0.04 to 0.07 g/cc for fibric peat, 0.09 to 0.21 g/cc for mesic peat, and averaged 0.26 g/cc for humic peat. Peats have a much lower bulk density than mineral soils, which usually exceed 1.0 g/cc.

3.3.4.1.5 Moisture retention. On a weight basis, peat is able to absorb and retain large quantities of water in comparison to mineral soils. Undecomposed peats can hold 15 to 20 times their own weight of water (Puustjarvi and Robertson 1975); upon air drying, absorption capacity is reduced by about 1/3. In contrast, well-decomposed peats can hold 4 to 8 times their weight of water; and upon air drying, the absorption capacity is reduced by as much as 80%.

On a volume basis, moisture holding capacity of peat is 2 to 3 times that of mineral soils (Puustjarvi and Robertson 1975). At saturation, moss peat holds 10% to 20% more water than sedge peat. At the drier end of the moisture scale, sedge peat can retain more moisture than moss peat. These differences are attributed to pore-size distribution upon air drying.

3.3.4.1.6 Saturated hydraulic conductivity. Saturated hydraulic conductivity is related to pore-size distribution, which varies with degree of decomposition (Boelter 1968, cited in Logan 1978). Data on saturated hydraulic conductivity from a number of studies (Logan 1978) indicate that, although water generally moves more rapidly through fibrous peat (higher hydraulic conductivity) and more slowly through more decomposed peat (lower hydraulic conductivity), there are large variations both within and between peat types.

The effect of drying on saturated hydraulic conductivity was monitored by Lindsay et al. (1976, cited in Logan 1978). Results indicated that both freeze- and air drying reduced hydraulic conductivity.

3.3.4.1.7 Summary. Table 32 summarizes some of the physical properties of peat in relation to degree of decomposition.

Table 32. Common values of some physical properties in relation to degree of decomposition.[a]

Type of peat (degree of decomposition)	Fibre content Rubbed	Fibre content Unrubbed	Bulk density (g/cc)	Maximum water holding capacity (% oven dry weight)	Total porosity (%)	Hydraulic Conductivity (cm/h)
Fibric	>4/10	>2/3	<0.1	>850	>90	>6.5
Mesic	4/10 to 1/10	1/3 to 2/3	0.1 to 0.2	450 to 850	85 to 90	0.1 to 6.5
Humic	<1/10	not applicable	>0.2	<450	<85	0.1

[a] Source: Logan (1978).

3.3.4.2 Effect of additions of peat on soil physical properties.

3.3.4.2.1 Bulk density. Adding peat to mineral soils decreases bulk density because porosity is increased, and because peat has a much lower particle density than mineral soil. Table 33 illustrates the decrease in bulk density with the addition of peat to sand. Even though reed-sedge peat is 3 times as dense as sphagnum peat, when added to sand, their effect on bulk density is similar, because the relative difference between sand and both peats is very large (Farnham 1968, cited in Logan 1978). Similarly, in all cases, adding peat to oil sand tailings sand resulted in decreased bulk density (Table 34; Logan 1978).

3.3.4.2.2 Porosity. Logan (1978) showed that the total porosity of tailing sand increased with additions of both moist and air-dried peat (Table 34). Air porosity also increased with the addition of both types of peat, but fibric peat had more of an effect. Adding more than 25% moist peat by volume resulted in little further increase in air porosity. However, increasing additions of air-dried peat resulted in increased air porosity at all rates.

3.3.4.2.3 Moisture retention. Stevenson (1974) indicated that with additions of peat, soil water retention as measured by percent dry weight increased for all three soils, and bulk density decreased (Table 35). On a volumetric basis, additions of peat caused increased water retention for the loamy sand at suctions below 1 bar, had no effect on the sandy loam, and caused decreased water retention

Table 33. Bulk density (g/cc) of sand as influenced by addition of two commercial peats.[a]

	Type of peat	
% (by volume) of peat added to sand	Sphagnum	Reed-sedge
0 (100% sand)	1.53	1.53
20	1.23	1.25
40	0.93	0.97
50	0.78	0.83
100 (100% peat)	0.04	0.14

[a] Source: Farnham (1968, cited in Logan 1978).

Table 34. Bulk density, total porosity, and air porosity of soil materials.[a]

		Moist samples		Dry samples	
Material	Bulk Density (g/cc)	Total Porosity (%)	Air porosity[b] (%)	Total Porosity (%)	Air porosity[b] (%)
Tailing sand[c]	1.36	nd[d]	nd[d]	36	6
Fibric (acid) peat	0.07	91	41	73	48
Mesic peat	0.12	81	22	96	45
Tailing sand + 25% fibric peat	1.17	51	19	58	14
Tailing sand + 50% fibric peat	0.94	58	21	71	27
Tailing sand + 75% fibric peat	0.47	72	28	77	39
Tailing sand + 25% mesic peat	1.12	59	14	56	15
Tailing sand + 50% mesic peat	0.84	70	21	68	22
Tailing sand + 75% mesic peat	0.48	80	18	78	31

[a] Source: Adapted from original table in Logan (1978).

[b] Air porosity is the percent of the total soil volume containing air when water is removed under 0.06 bar moisture tension.

[c] Oil sand tailings from Fort McMurray, Alberta (Great Canadian Oil Sands (GCOS) Ltd. tailing dyke).

[d] Not determined.

Table 35. Soil water retention of soil-peat mixtures on a % dry weight basis, and on a volumetric basis.[a]

Soil type	Peat moss added (% dry weight)	Bulk density (g/cm^3)	Soil water suction (bars)						
			0.1	0.2	0.3	0.5	1.0	5.0	15.0
			% dry weight basis						
Loamy sand	0	1.46	8.4	6.6	5.9	5.1	4.5	4.2	3.7
	1	1.41	10.0	7.8	6.7	5.9	5.2	4.5	4.2
	3	1.31	13.8	10.3	8.9	7.3	6.4	5.7	5.5
	5	1.21	15.4	11.5	10.3	8.2	7.8	6.6	6.2
Sandy loam	0	1.20	33.9	16.9	12.7	10.6	8.9	8.1	7.8
	1	1.17	35.2	18.8	14.2	11.7	10.0	9.0	8.6
	3	1.09	37.2	19.9	15.5	12.9	11.3	10.0	9.9
	5	1.02	40.4	23.0	19.0	15.9	13.4	11.9	11.0
Silt loam	0	1.16	42.5	34.2	29.8	23.9	18.8	9.0	6.0
	1	1.11	45.0	35.9	30.9	25.1	19.0	11.5	10.0
	3	1.02	47.7	39.0	33.7	27.2	21.0	13.4	11.4
	5	0.96	50.9	40.9	34.8	28.1	22.8	15.0	12.5
			% by volume						
Loamy sand	0	1.46	6.8	4.4	3.3	2.2	1.3	0.3	nd[b]
	1	1.41	8.3	5.2	3.7	2.5	1.2	0.2	nd
	3	1.31	11.0	6.2	4.4	2.6	1.2	0.2	nd
	5	1.21	11.2	7.0	5.1	3.2	2.1	0.6	nd
Sandy loam	0	1.20	31.4	11.0	5.8	3.3	1.7	0.3	nd
	1	1.17	33.1	11.6	6.7	3.7	1.7	0.6	nd
	3	1.09	30.2	11.0	6.2	3.3	1.7	0.2	nd
	5	1.02	30.1	12.2	8.2	5.0	2.5	0.9	nd
Silt loam	0	1.16	42.6	32.7	27.7	21.3	14.4	3.5	nd
	1	1.11	38.8	28.7	23.2	17.0	10.7	2.0	nd
	3	1.02	37.3	27.8	22.8	18.0	10.8	2.2	nd
	5	0.96	37.2	26.7	21.7	16.0	10.3	2.7	nd

[a] Source: Stevenson (1974).

[b] Not determined. Additions of peat may increase, decrease or have no effect on stored soil water, depending on the texture of the soil (Stevenson 1974).

of the silt loam. Data from this study also suggested that additions of peat decreased pore-size diameter in coarse-textured soils, had minimum effect in intermediate-textured soils, and increased pore-size diameter in fine-textured soils.

Logan (1978) showed that available water content increased with additions of moist peat to tailing sands in Alberta (Table 36). Mesic peat had a lower air porosity, and less gravitational drainage, and therefore larger amounts of available moisture than fibric peat. Additions of air-dried peat increased air porosity and allowed more rapid drainage, which decreased the amount of available water, an effect more noticeable for fibric peat than for mesic peat.

3.3.4.2.4 Hydraulic conductivity. Logan (1978) examined the effect of peat amendments on hydraulic conductivity of a tailing sand (Table 36). Decreased hydraulic conductivity with increasing degree of decomposition is consistent with the relationship of hydraulic conductivity to volume, size and distribution of pores. Additions of moist fibric peat did not significantly affect hydraulic conductivity, and only the largest addition of moist mesic peat significantly lowered hydraulic conductivity. Only the addition of air-dried peat at 75% by volume resulted in significantly increased hydraulic conductivities.

3.3.5 Biology

3.3.5.1 Biology of peat. Kong et al. (1980) found the highest bacteria numbers in less acidic, more readily decomposable fen peats from two locations in Alberta, compared to more acidic fibric and mesic peats from the same areas (Table 37). Fibric sphagnum peat from Mildred Lake in northeastern Alberta had low numbers of both bacteria and fungal colony forming units due to low pH of the material which inhibits bacterial growth, and anaerobic conditions which inhibit fungi growth. Mesic peat had somewhat higher bacterial numbers. At Evansburg, west of Edmonton, numbers of fungi and bacteria were higher, possibly due to the higher percentage of woody materials in the peat at this site. Once removed from its cold, wet environment, both numbers and types of microorganisms can be expected to change dramatically.

In general, the rate of biological decomposition of peat materials per unit of carbon appears to be slower than for other plant materials, which may be due to the presence of inhibiting phenolic substances (Ivarson 1977, cited in Kong et al. 1980), low temperatures and anaerobic conditions.

Table 36. Available water content and hydraulic conductivity of soil materials.[a]

Soil material	Available water (% by volume)		Hydraulic conductivity (cm/h)	
	moist	air-dried	moist	air-dried
Tailing sand[b]	nd[c]	2	nd	46
Fibric (acid) peat	10	4	203	283
Mesic peat	12	11	10	200
Tailing sand + 25% fibric peat	3	3	50	59
Tailing sand + 50% fibric peat	5	2	45	49
Tailing sand + 75% fibric peat	7	0	54	105
Tailing sand + 25% mesic peat	6	3	40	50
Tailing sand + 50% mesic peat	13	5	36	42
Tailing sand + 75% mesic peat	24	9	13	65

[a] Source: Logan (1978).

[b] Oil sand tailing sand from Fort McMurray, Alberta (Great Canadian Oil Sands (GCOS) Ltd. tailing dyke).

[c] Not determined.

Table 37. Distribution of microorganisms in peats.[a]

Peat Type	Bacteria (no./g dry peat)	Fungi (CFU[b]/g dry peat)
Mildred Lake		
Fibric	28 X 10^4	2.1 X 10^4
Mesic	200 X 10^4	2.8 X 10^4
Fen	1600 X 10^4	27 X 10^4
Evansburg		
Fibric	590 X 10^4	37 X 10^4

[a] Source: Adapted from original table in Kong et al. (1980).

[b] Colony forming units.

3.3.5.2 Effect of additions of peat on soil biology and plant growth.

3.3.5.2.1 Effect on soil biology. In general, because the addition of peat to soil improves aeration and available water, it will stimulate microbial activity, as measured by the mineralization of carbon as carbon dioxide (CO_2). Compared to other carbon containing amendments, well-decomposed peats may not cause nitrogen immobilization because much of the carbon is unavailable. If microbial activity is increased, both the number and diversity of other organisms (soil fauna) will also increase. Visser et al. (1978) found that peat used as an amendment for surface coal mine reclamation increased bacterial numbers compared to unamended controls, but only to the depth of amendment, 15 to 25 cm.

3.3.5.2.2 Plant growth. Logan (1978) conducted a greenhouse experiment to determine the influence of peat additions on fertility of tailing sands accumulated from surface mining of the Alberta Oil Sands. Plant yields on tailing sand and mixtures of tailing sand and all three peats were low. However, the mesic peat produced greater yields than other materials. Fertilization and liming resulted in significant yield increases for all soil materials except the fibric (acid) peat.

Because peats are inferior to other amendments as a source of plant nutrients, the beneficial effects of peat addition are due mainly to their physical effects on soils or tailings sands.

3.3.6 Recommendation for Application

From results of the literature review, some general recommendations can be made.

3.3.6.1 Rates. Peat is commonly used as an amendment to overburden materials for reclamation by Syncrude in Fort McMurray (E. Anderson, Syncrude, Fort McMurray, Alberta, telephone conversation, December 17, 1992). Freshly excavated peat materials are spread and worked into the top 20 cm to achieve approximately 20% by volume organic matter. More work needs to be carried out to determine effective rates for other types of soil and disturbances. From work by Logan (1978), it appears that at least 25 cm of peat should be incorporated into tailing sands if the amendment is to be effective. We could find no other information on recommended addition rates of peat to soil in Alberta, or under similar conditions elsewhere.

3.3.6.2 Frequency. Peat can be added to the soil as often as required, but care must be taken to counteract acidity with additions of lime. If the peat is relatively undecomposed, the carbon to nitrogen ratio of the material may have to be adjusted with nitrogen fertilizer to a ratio of about 25:1. Because peats are relatively low in plant nutrients, mineral fertilizers will likely be beneficial.

3.3.6.3 Equipment and methods. Syncrude has found that incorporation of peat into overburden with a disc provides better mixing than with either a cultivator or rotovator (E. Anderson, Syncrude, Fort McMurray, Alberta, telephone conversation December 17, 1992). No other information on methods and equipment was found. Incorporating peat into the soil is preferable to using peat as a surface mulch.

3.3.7 Costs. Commercial peats are available from producers for \$21 to \$24/m^3 (\$16 to \$18 /yd^3). As producers are mainly in northern half of Alberta, hauling costs may limit the use of peat in southern Alberta.

3.3.8 Longevity of effect

No long term studies on the duration of effect of peat additions appear to have been carried out. Because carbon to nitrogen ratios of peat are relatively low, and decomposition rates are slow, it can be expected that peats should be one of the more long-lasting of the organic amendments. Allison (1973, cited in Logan 1978) for example, suggested that positive physical effects gained through additions of peat to soil can be expected to last for several years, since 90% of peat was found to remain after the first season. The physical benefits should be especially long-lived if partially decomposed or well decomposed peat is used, since most of the readily available carbon materials have already decayed, and the remaining more resistant materials will take much longer to decay.

3.3.9 Summary

3.3.9.1 Benefits. Using peat as a soil amendment has the following benefits:

1. Peat improves physical conditions (tilth) of the soil;
2. Peat increases water holding capacity of the soil;
3. Peat provides humus and a modest nutrient source; and

4. Peat is longer lasting than other organic amendments.

Greatest benefits are gained when peat is mixed into very sandy or heavy clay soils and least benefits are gained on loam soils. Benefits of peat amendments are not permanent. Peat amendments do not provide a permanent increase in soil organic matter. The establishment of plants on the soil is important for the long term maintenance of adequate soil organic matter levels. Growing plants will add a continual supply of carbon to the soil.

3.3.9.2 Drawbacks. Using peat as a soil amendment has the following drawbacks:

1. Peat is a poor source of plant nutrients compared to other organic amendments. High rates of fertilizer are often needed;
2. Because many peats are acidic, lime may be needed;
3. Micro-nutrient deficiencies may be a problem on some soils;
4. High rates are often needed for benefits to become obvious; and
5. Benefits with air-dried peat are less than with moist peat. Air-dried peat requires careful handling.

Peat is very slowly decomposable. As a result peat will remain unaltered by soil organisms for a long time. Therefore, peat is not as useful as some other materials for stimulating biological activity or for increasing nutrient cycling and availability. They still, however, impart desirable physical and chemical effects to the soil.

3.3.10 Use for Reclamation

In Alberta, peat is used regularly as an amendment mainly for reclaiming overburden from surface mining in the Alberta Oil Sands near Fort McMurray (E. Anderson, Syncrude, Fort McMurray, Alberta, telephone conversation December 17, 1992). It has also been used as an amendment on some petroleum leases, but no cases appear to have been documented (D. Headdon, Western Oilfield Environmental Services, Calgary, telephone conversation October 19, 1992).

Use of peat for amending tailing sands in the Ft. McMurray area results in improved moisture conservation, reduction in erodibility (reduced splash erosion and impeded surface water flow), increased soil fertility, and increased plant growth (Logan 1978). In his study examining the use of several types of peat to amend tailing sands, Logan (1978) found that the effectiveness of peat additions was influenced by the type of peat applied. Mesic peat was more effective than fibric peat for improving available water storage capacities, reducing evaporation, reducing wind erosion, supplying organic matter, supplying and retaining plant nutrients and increasing soil buffering capacity. All treatments required additions of fertilizer to increase plant growth, regardless of peat type. Acidic peat treatments required lime as well.

Mulch applications were found to be more effective than mixed-in peat applications for controlling water erosion and moderating soil temperatures (Logan 1978). However, mixed-in applications of peat retained more available water, encouraged deeper rooting, and distributed nutrients through the root zone. This study suggested that applications of 25 cm of mesic peat may be required to improve moisture retention, ensure optimum plant growth, and stabilize tailing sand. Greater amounts of fibric peat than mesic are required to attain the same effects, because of lower density, nutrient content, and available water holding capacity of fibric peat. Less is needed (12 cm) if mulch applications are used to reduce erosion (Logan 1978).

Results of another study at Syncrude of various mixtures of clay overburden and peat as amendments to tailing sands, showed that plant available soil moisture content increased notably with peat application but decreased with overburden application (HBT AGRA Limited 1992). Organic carbon content, total and available nitrogen and sulphur increased with peat application. Herbaceous plant cover increased substantially with peat and overburden application, and survival rate of most trees and shrubs was slightly higher with increased peat application. HBT AGRA Limited 1992 recommend the use of the highest rate of peat (minimum 4% organic carbon) incorporated to 40 cm to optimize plant growth.

At Highvale Mine in north central Alberta, Bateman and Chanasyk (1992) examined the effects of using peat and manure along with deep ripping as amendments to reclaim coal mine spoil. Deep ripping, alone, can result in increased clay content, plasticity index and surface crusting potential of the Ap horizon. Both peat and manure amendments were effective in ameliorating these effects.

Peat has also been used as an amendment on coarse taconite tailings from iron ore production in northern Minnesota. As peat addition rates increased, pH decreased, and total organic carbon, organic nitrogen, soil organic matter, and extractable phosphorous concentrations increased. Incorporation of peat significantly increased total plant density. Peat increased plant cover when applied at a rate of 89.6 Mg/ha with at least 224 kg/ha of 18-46-0 fertilizer (Norland et al. 1991).

3.3.11 Recommendations for Use in Alberta

1. The pH of the peat to be used is critical. Lime requirements must be calculated for each site based on the pH of the peat material, amounts to be added, and initial pH of the soil to be amended. A "lime requirement" measurement should be made on mixtures of proposed peat and soil material to which it is to be added;
2. Mesic peat is more effective as a soil amendment than fibric peat;
3. The carbon to nitrogen ratio of undecomposed peat to be used as an amendment is important, as sufficient nitrogen fertilizer may need to be added to reduce the ratio to about 25:1. However, some peats have sufficient N supplying power despite their relatively high carbon to nitrogen ratio. Consequently, the N mineralization rate should be measured on the proposed peat;
4. Moist peat which has never been dried is a more effective amendment than air-dried peat;
5. Incorporating 25 cm of peat into tailing sands appears to be effective. More work is needed to determine effective rates for other types of soil and disturbances;
6. In most cases, nitrogen, phosphorus and potassium fertilizers will be needed along with the peat amendment because peats are relatively low in nutrients. Where peat is being used to amend infertile materials (sands for example) micronutrients may also have to be added; and
7. Mulching with peat has advantages for controlling water erosion and moderating soil temperatures. Incorporation is preferred for improving soil characteristics for plant growth.
8. Layering should be avoided because of the negative effect on vertical moisture movement.

3.4 WOOD WASTE

Wood waste includes a wide variety of by-products of the forest industry. It is generally disposed of by burning (dry waste) or landfilling (dry waste and sludge). Spreading wood waste sludges on land has been proposed as an alternative to landfilling. The sludge could supply a part of the nutrient requirements of a crop (Simpson et al. 1982, cited in Zibilske 1987). Dry wastes have also been used on the surface of the soil as a mulch, or incorporated into the soil as a conditioner. Wood wastes that are used as a mulch are considered to be a soil amendment for the purposes of this review, because mulches ultimately become incorporated into the soil by mixing or decomposition.

Much of the information on the use of wood waste as a soil amendment during reclamation is from the mining industry in the western United States.

3.4.1 Types

Wood wastes come from a variety of forest industries, including pulp mills, saw mills, and wood product (e.g., fibreboard) processing plants. Wastes from sawmills and pulp mills have the most potential for use in reclamation, and most of the available literature deals with such wastes. West and Bishop (1987) list a number of major waste products from pulp mills, that could be used as a soil amendment. These include knots (most often used as a fuel, therefore rarely a waste), clarifier sludge (broken wood fibres that collect in the bottom of the clarifier; they comprise 10% of mills' wood waste), and grit (bark, branches, stones, and soil from the grit chamber; comprising 80% of mills' wood waste). Sawmill wastes include millrun, gangrun, and resaw sawdust; shavings; wood chips; and bark.

In Alberta, residue from sawmills includes bark, fine chips, shavings, sawdust, and other residues such as log and lumber trim ends, yard waste, reject logs, and portions of logs. Residues from panelboard mills include yard wastes, sander dust, plywood and panel trim, reject board, and other dry and green residues (Silvacom Ltd. 1991).

3.4.2 Sources

In all, almost 2 million oven dry Mg of wood wastes are produced in Alberta yearly. Only about 27% of this is utilized. Table 38 indicates that almost 1 400 000 tonnes of the oven dry wood wastes produced yearly in Alberta are not currently being utilized (Silvacom Ltd. 1991). Currently about 85% is burned. The “ Other disposal" category includes some agricultural uses,

Table 38. Utilization and disposal of wood residues in Alberta.[a]

Utilization/disposal Method	Annual tonnage processed (O.D. tonnes/year)
Utilization	
Power boilers	354 390
Other burners (energy used in process or buildings)	48 585
Agricultural uses	39 018
Panelboard uses	88 155
Subtotal	530 148
Disposal	
Beehive burners	995 393
Silo burners	173 622
Landfill	151 059
Stockpile	72 555
Other disposal	7 013
Subtotal	1 399 642
TOTAL	1 929 789

[a] Source: Silvacom Ltd. (1991).

mainly use of shavings and sawdust for animal bedding. Silvacom Ltd. (1991) indicates that some sawmill residues are used as a soil additive or for horticultural application, but no examples are documented. Figure 9 illustrates the amount of wood waste potentially available to major centres in Alberta, using a 50 km accumulation radius.

3.4.3 Chemistry

There is little comprehensive information about the chemistry of wood waste materials, and the effects on soils of using wood wastes as an amendment. The information available indicates that the materials are highly variable. If wood waste is used as an amendment, application of additional nitrogen is necessary to avoid a long period in which soil nitrogen is unavailable to plants.

3.4.3.1 Chemistry of wood wastes. The chemical properties of wood wastes depend on the origin of the wood material and on the type of waste produced. For example, cellulose, hemicellulose, lignin, and extractives comprise 50%, 10%, 25% and 10% by weight, respectively, for pine and spruce (Wenzl 1970, cited in Reardon and Poscente 1984). These four component groups are made up of carbon (50%), oxygen (44%), hydrogen (6%), and traces of nitrogen. The chemical compositions of sawdust, shavings, and bark would be similar.

Chemical properties of three different sources of papermill sludge are presented in Table 39. Except for pH and nitrogen percentage, chemical characteristics were quite variable among sources. Concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium for the oven dry Ohio sludge (Vogel and Rothwell 1988) were much higher than for the other two sludges. Heavy metal concentrations were low for the 30% dry Ohio sludge and the Maine sludge (Watson and Hoitink 1985), and utilization of the sludge was not considered to be limited by heavy metal content (Zibilske 1987).

Carbon and nitrogen contents for various farm and forest products used as mulches or soil conditioners are compared in Table 40. Total carbon content for wood products is generally high (50% or greater), while nitrogen is usually low (< 0.35%). This results in a very high carbon to nitrogen ratio for the forest products, ranging from 134 to 1244. When carbon to nitrogen ratio is greater than 25:1, microorganisms involved in decomposition compete with plant roots for available nitrogen (Bollen and Glennie 1961). This causes immobilization of soil ammonium (NH_4^+) and nitrate (NO_3^-), thereby reducing the nitrogen-supplying power of the soil to plant roots.

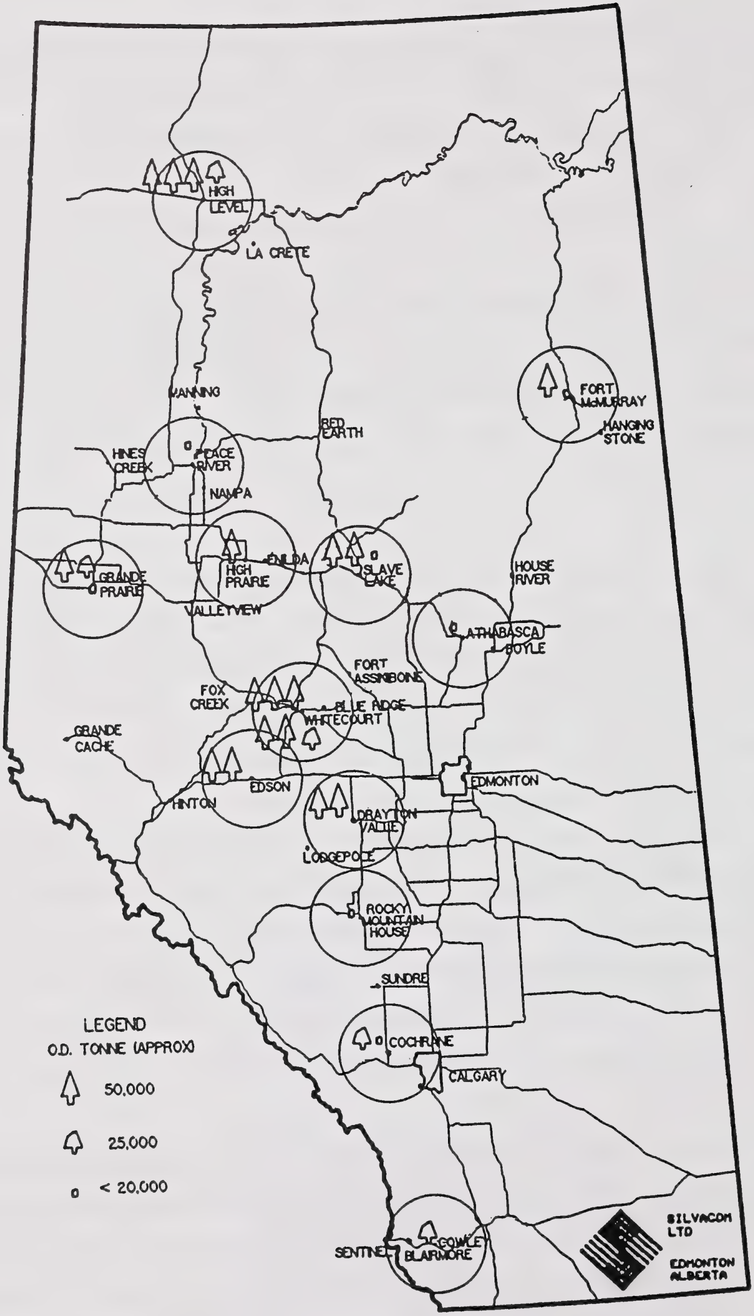

Figure 9. Wood residues available to major centers using a 50 km accumulation radius.[a]

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[a] Source: Silvacom Ltd. (1991).

Table 39. Chemical properties of papermill sludge from 3 different sources.

Parameter	Papermill Sludge		
	Ohio[a]	Maine[b]	Ohio[c]
pH	7.6	7.6	7.5-8.6
N %	1.06	0.08	0.35-0.7
P (ppm)	1825	0.12	20-50
K (ppm)	2575	230	231-411
Ca (ppm)	197 897	81 000	2705-5820
Mg (ppm)	5798	3150	635-874
Organic C %	nd[d]	38.3	nd
C %	nd	nd	11.2-17.2
Fe (ppm)	4425	nd	nd
Al (ppm)	23 026	nd	nd
Mn (ppm)	nd	nd	34-40
Zn (ppm)	nd	40.0	20-86
Cd (ppm)	nd	0.3	0.1-15
Ni (ppm)	nd	7.6	35-63
Pb (ppm)	nd	nd	28-37
B (ppm)	nd	nd	0.6-0.7
Cr (ppm)	nd	3.6	nd
Cu (ppm)	nd	58.0	nd
SO_4 (ppm)	nd	13.1	nd

[a] Adapted from original table in Vogel and Rothwell (1988) for oven dry material from Ohio.

[b] Adapted from original table in Zibilske (1987) for fresh material from Maine.

[c] Adapted from original table in Watson and Hoitink (1985), for material with 30% dry solids from Ohio.

[d] Not determined.

Table 40. Carbon and nitrogen in farm and forest products used as mulches and soil conditioners.[a]

Material	Ash %	Total Carbon %	Kjeldahl Nitrogen %	C:N Ratio
Alfalfa hay	8.79	43.15	2.34	18
Pea vines	8.50	44.02	1.50	29
Wheat straw	8.54	44.70	0.12	373
Douglas-fir Bark				
Young	0.69	51.66	0.17	304
Old	0.57	58.56	0.20	293
Douglas-fir sawdust				
Mill run, fresh	1.48	51.00	0.07	728
Mill run, 2 months old[b]	1.61	49.98	0.08	625
Mill run, 3 years old[b]	7.99	47.01	0.33	142
Sawdust, resaw				
Douglas-fir	0.17	49.80	0.05	996
Red alder	1.21	49.63	0.37	134
Western red cedar	0.29	51.05	0.07	729
Western hemlock	0.35	49.74	0.04	1244
Ponderosa pine	0.33	53.18	0.05	1064
Sitka spruce	0.22	51.50	0.05	1030
Moss peat	3.12	48.29	0.83	58

[a] Source: Bollen (1953).

[b] Weathered.

Harmon et al. (1986) lists a number of factors that control the decomposition of wood wastes. Temperature controls the rate of microbial action in the soil. Most wood-decaying fungi have a temperature optimum of 25°C to 30°C (Kaarik 1974, cited in Harmon et al. 1986). Between 13°C and 30°C fungal respiration rate approximately doubles for each 10°C increase (Deverall 1965, cited in Harmon et al 1986). Moisture is limiting if either extremely high or extremely low (Kaarik 1974, cited in Harmon et al. 1986). Oxygen and carbon dioxide influence what species of organisms are present and at what rate they can degrade woody wastes. However, little work has been done to monitor oxygen and carbon dioxide concentrations, or their controlling factors (Harmon et al. 1986). The high lignin content of woody materials is one of the main reasons why decomposition is so slow (Alexander 1977).

Once wood waste has been composted, many chemical properties are dramatically altered, particularly the carbon to nitrogen ratio. Ndayegamiye and Isfan (1991) found that after 36 months of composting, the carbon to nitrogen ratio of wood shavings was reduced from 43 to 17, and that of sawdust was reduced from 48 to 35. Microbial respiration rates, pH, and NO_3-nitrogen all increased during composting. None of the materials were phytotoxic at any stage in the composting process.

3.4.3.2 Effect of wood waste on soil chemistry.

3.4.3.2.1 Organic matter, nitrogen, and carbon to nitrogen ratio. Because of the high carbon to nitrogen ratios of most wood wastes, supplemental nitrogen is required to maximize decomposition in most soils (Aspiarte et al. 1973, cited in Zibilske 1987). In an incubation study, for example, Simpson et al. (1982, cited in Zibilske 1987) noted that soil amended with papermill sludge immobilized soil nitrogen for 2 weeks.

In another laboratory study, Zibilske (1987) found that samples displayed nitrogen immobilization directly proportional to rates of sludge addition. At the very highest sludge rates (133 and 267 g/kg soil), there was a significant increase in organic matter content. Zibilske (1987) concluded that papermill decomposition may create nitrogen deficiency in soil ranging from 9 to 14 mg/kg or more after 250 days incubation.

3.4.3.2.2 Other nutrients and heavy metals. Voorhees and Uresk (1990) carried out a field study in Wyoming to determine the effects on soil chemistry of three amendments (gypsum, fertilizer, and ponderosa pine sawdust with added nitrogen), alone and in combination, on chemical properties of bentonite mine spoil (Table 41).

Amendments of wood waste plus added nitrogen resulted in mean total nitrogen, extractable P, and extractable K in spoil which were 86%, 40%, and 33% higher, respectively, than means for spoil from plots that received no wood waste. Wood waste plus nitrogen also increased the extractable concentrations of cadmium and nickel, although not to levels expected to have any effect on plant growth. Wood waste plus nitrogen treatment increased water infiltration into spoil, as indicated by increased solubilization of gypsum. Amendments of wood waste plus nitrogen were also found to increase the effects of both fertilizer and gypsum applications.

3.4.3.2.3 Soil pH, salinity, and sodicity. Another study on bentonite mine spoil in Wyoming found that wood waste (45% Ponderosa pine bark, 20% wood chips and 35% sawdust) applied at rates rates of 45, 90 and 135 Mg/ha improved spoil water regimes and ameliorated soil salinity problems (Belden et al. 1990). Nitrogen fertilizer was applied to maintain a uniform carbon to nitrogen ratio across treatments. Results indicated that the electrical conductivity (EC) generally decreased, as a result of leaching, at depths of 0 to 15 cm as wood waste rates increased. EC levels at depths of 15 to 45 cm did not change. Belden et al. (1990) also found that water soluble cations (sodium, calcium, magnesium, and potassium) generally decreased at depths of 0 to 15 cm as wood waste rates increased. This effect was not as pronounced for calcium as for the other elements. There was little effect at depths of 15 to 45 cm. SAR increased for all wood waste rates, the reverse of the trend for soluble cations and EC, because the proportion of the total pool of Na leached was smaller than the proportions of the total pool of Ca and Mg leached (Belden et al. 1990). The increase in SAR suggests that there is a need for addition of Ca to promote long term amelioration of sodicity when wood wastes are used to amend saline and sodic soil. Soil pH increased at lower spoil depths from 7.02 at 0 to 15 cm depths to 7.26 at 30 to 45 cm depths. In contrast, Voorhees and Uresk (1990) found that pH decreased with additions of wood waste at both 0 to 10 cm and 10 to 20 cm depths (Table 41).

3.4.4 Physical Properties

Very little information is available concerning the physical properties of wood waste materials. Physical properties can be expected to vary with the type of material, handling, and source.

Table 41. Chemical characteristics of unamended and amended spoil (after two years) averaged across treatments, with and without wood residue.[a]

Chemical Property	Spoil depth					
	0 to 10 cm			10 to 20 cm		
	unamended spoil	with wood residue	with other amendments	unamended spoil	with wood residue	other amendments
N (ug/g)	0.5	1.3	0.7	0.4	0.7	0.4
P (ug/g)	11.0	21.0	15.0	10.0	14.0	12.0
K (ug/g)	201.0	263.0	198.0	202.0	196.0	180.0
Zn (ug/g)	4.0	4.1	3.9	5.2	4.7	5.4
Fe (ug/g)	44.4	40.9	46.6	37.7	40.7	33.6
Mn (mu/g)	6.7	30.6	9.8	4.7	13.4	8.7
Cu (ug/g)	2.7	2.6	2.5	2.1	2.0	1.7
Pb (ug/g)	1.9	1.7	1.8	2.3	1.9	2.3
Cd (ug/g)	0.11	0.17	0.12	0.09	0.11	0.09
Ni (ug/g)	1.5	2.1	1.6	1.2	1.4	1.1
Mo (ug/g)	0.36	0.25	0.34	0.66	0.46	0.68
Na (ug/g)	6477	5150	5400	7798	5963	6178
B (ug/g)	0.1	0.1	0.1	0.2	0.1	0.2
soluble Ca (meq/l)	3.5	11.9	7.3	2.1	7.2	4.1
Soluble Mg (meq/l)	1.6	3.4	2.0	1.2	5.2	4.5
Soluble Na (meq/l)	38.2	43.3	46.9	30.5	5.7	6.2
SAR	25.9	18.7	23.4	24.7	23.6	28.3
SO_4 (ug/g)	2110	3711	3475	2295	2868	2828
EC (dS/m)	0.40	5.1	5.1	0.31	5.0	4.9
CEC (cmol/kg)	52.8	48.9	46.3	59.2	48.8	54.8
pH	7.6	7.1	7.4	8.3	8.2	8.5

[a] Source: Voorhees and Uresk (1990).

3.4.4.1 Physical properties of wood wastes. Particle size is important in determining the kind of use wood waste can be put to as a soil amendment. Chips, shavings, millrun sawdust and gang sawdust make good mulches because of their large particle size. Resaw sawdust packs more tightly because of smaller particle size, and its use may retard aeration and moisture retention. All kinds of sawdust can be used for incorporation into soil, but chips and thick shavings may be too coarse for this purpose and would be better used as mulch (Bollen and Glennie 1961). A fine particle size greatly increases the decomposition rate of wood in soil. Particle size fractionation for some forest products, using Tyler standard screens, are shown in Table 42.

Table 42. Particle size fractionation of sawdust.[a]

	Percentage retained on Tyler standard screens of indicated mesh									
	5	10	20	40	60	80	100	150	200	>200
Sawdust										
Douglas-fir mill run	17.7	18.6	33.2	18.1	5.6	2.6	1.8	1.8	0.7	0.6
Douglas-fir gang saw	0.0	29.3	40.9	23.3	3.3	1.3	0.6	0.5	0.5	0.2
Hemlock, gang saw	0.0	30.3	41.7	20.9	3.6	1.3	0.5	0.5	0.4	0.3
Cedar, gang saw	0.0	30.6	43.2	18.9	4.9	1.3	0.8	0.5	0.3	0.1
Pine, resaw	0.0	0.0	35.7	46.6	11.3	3.0	1.2	1.1	0.7	0.7
Oak, resaw	0.0	0.1	45.1	38.8	8.1	3.2	1.1	1.7	0.8	1.0

[a] Source: Bollen and Glennie (1961).

3.4.4.2 Effect of wood waste on soil physical properties. Incorporation of wood waste was found to increase soil moisture content. Belden et al. (1990) found that incorporation of the two highest rates of wood waste (90 and 135 Mg/ha) into spoil significantly increased spoil water content at the depths of 0 to 15 cm for three of four years. Wittwer et al. (1980), working on minespoil in Kentucky, found that spoil moisture content at a depth of 15 cm was highest under a bark mulch and lowest on the control. A hard wood bark mulch was applied at 80 Mg/ha (5 cm deep). Graves and Carpenter (1978), also working in Kentucky, used sawmill residue as the mulching medium on surface mine spoil. Mulch was applied at rates of 12.7 to 101.6 mm (0.5 to 4 inches). Significant increases in spoil moisture occurred with increasing mulching depths above 25.4 mm (1 inch) (Graves and Carpenter 1978).

Hardwood bark, wood fibre, and straw mulches lower soil surface temperatures. Wittwer et al. (1980) working in Kentucky, found that temperatures near the surface (7.5 cm) were highest for the control and lowest for the hardwood bark mulch. Graves and Carpenter (1978) found that additions of mulch, to a maximum of 50.8 mm (2 inches), significantly decreased the spoil temperature compared to non-mulched areas.

Incorporated papermill sludge may provide erosion control. Watson and Hoitink (1985) observed that papermill sludge applied at a rate of 168 dry tonnes/ha (150 dry tons/acre) used to amend 1:4 stripmine slopes provided a measure of erosion control, if the sludge was incorporated. Wood fibres in the sludge formed a sheet-like layer on the surface of the spoil which reduced erosion compared to areas treated with topsoil. Seedling emergence was not affected.

3.4.5 Biology

3.4.5.1 Biology of wood waste degradation. Degradation of wood under climate conditions in Alberta is accomplished by numerous fungi and bacteria. Harmon et al. (1986) list bacteria, soft rots, brown rots and white rots as the organisms chiefly responsible for breaking down woody cell walls. Fungi are chiefly responsible for degradation of larger wood particles. Cellulose is degraded by both aerobic and anaerobic microbes yielding degradation products that are easily oxidized to carbon dioxide and water (Reardon and Poscente 1984). Lignin, the most resistant organic residue, is normally unaffected by anaerobic bacteria (Sen 1960, cited in Reardon and Poscente 1984). However, under aerobic conditions, lignin is degraded to complex humic substances. Humus is slowly decomposable and represents a store of slowly but continually available nitrogen as long as crop residues are returned to the soil (Bollen and Glennie 1961). Decomposition of lignin is accomplished mainly by white-rot fungi. Brown-rot fungi degrade the polysaccharides associated with lignin in wood (Paul and Clark 1989). The rate of decomposition of wood wastes is slow, which is advantageous in providing long lasting mulches and more prolonged effects on incorporation into the soil.

3.4.5.2 Nature of effect on soil biology and plant growth.

3.4.5.2.1 Soil biology. Little field information is available from the literature, none from the northern Great Plains region. However, application of wood waste to soils will affect soil biology. For example, in a greenhouse pot study on acid spoils (Vogel and Rothwell 1988), formation of endomycorrhizae in plants was increased by all rates of papermill sludge when compared to a lime-fertilizer treatment (Table 43). The significance of the formation of endomycorrhizae was most apparent where nutrient levels in soil limited plant growth. The extensive mycelium of endomycorrhizae permeated the soil increasing the capacity of the host plant to absorb nutrients. Where plant nutrient concentrations were high in the soil, little plant-fungal association was observed.

3.4.5.2.2 Plant growth. A plot study in Wyoming that examined plant response to the use of wood wastes as an amendment on bentonite mine spoil found that the highest rates of wood waste produced the best results (Belden et al. 1990; Moore et al. 1991; Smith et al. 1985, 1986). These results were believed to occur because of increased water infiltration and storage and leaching of salts in the root zone at high rates of wood waste additions. Maximum plant productivity occurred at 90 Mg/ha wood waste for native species and at 135 Mg/ha wood waste for introduced species (Smith et al. 1986). However, maximum diversity occurred at lower rates (45 Mg/ha and 90 Mg/ha wood waste for native and introduced species, respectively). Belden et al. (1990) found that although after the third growing season, plant productivity still responded positively to increased wood waste rates (Table 44), by the fifth year, only the 135 Mg/ha wood waste rate produced significantly greater yields compared to the other treatments. The lack of response in the fifth year may reflect the increased soil sodicity that had occurred. When gypsum was included as a third soil amendment, perennial grass growth continued to be enhanced by wood waste amendment (Moore et al. 1991). The study concluded that up to 90 or 135 Mg/ha of wood waste may be necessary for long-term enhancement of plant growth. The addition of surface-applied gypsum reduced spoil sodicity during the seventh through ninth years, resulting in enhancement of plant growth during these years.

In a study in Quebec, Ndayegamiye and Dube (1986) examined the effects of bark and pig manure on crop yields and soil chemical characteristics. It was found that bark incorporated alone resulted in strong nitrogen immobilization, which depressed crop yields. Soil organic matter content increased slowly over 4 years when bark and manure were applied together. Bark alone decomposed very slowly, and nitrogen immobilization effects persisted into the fourth year. The

Table 43. Incidence of vesicular-arbuscular mycorrhizal (VAM) fungi in roots of plants grown in greenhouse pots treated with papermill sludge, lime and fertilizer.[a]

Treatment and Rates	Hang Rock Spoil	Weltzheim Spoil
Lime + fertilizer	27%	28%
Sludge - 25g/1000 g spoil	96%	77%
Sludge - 50g/1000 g spoil	54%	84%
Sludge - 75/1000 g spoil	95%	98%

[a] Adapted from original table in Vogel and Rothwell (1988).

Table 44. Perennial grass productivity[a] (kg/ha) in response to wood residue rates on a bentonite mine spoil in Wyoming.[b]

	Wood Residue Rate (Mg/ha)[c]			
Growing Season	0	45	90	135
Second	59	669	1748	2550
Third	80	361	1220	1956
Fourth	10	55	148	448
Fifth	15	116	324	886

[a] Averaged across species mixture and N-fertilizer treatment.

[b] Adapted from original table in Belden et al. (1990).

[c] $LSD_{.05}$ = 481 among wood rates within a year.

authors concluded that bark application with pig manure as nitrogen source may improve long-term soil productivity.

3.4.6 Application Methods and Timing

3.4.6.1 Methods. Wood wastes can be incorporated into the soil as a conditioner or spread on the surface as a mulch. However, unless the material is incorporated into the soil, its use as a soil amendment appears to be limited. For example, Watson and Hoitink (1985) in Ohio found that if papermill sludge was incorporated on a strip mine spoil by discing and rototilling, root penetration was greater than if the sludge was applied to the surface. They state that in Ohio, discing is the practice most commonly used for reclamation in 1985.

3.4.6.2 Timing. Fall application of wood waste to the soil appears to be preferable. Timing of application of wood wastes to Wyoming bentonite mine spoil was studied by Voorhees et al. (1987), in relation to the growth of rillscale, an annual forage invader. After two growing seasons, fall-applied amendments, either with sawdust alone or sawdust in combination with gypsum or fertilizer, resulted in increased peak and end-of-season standing crop, plant height, and canopy cover. Spring-applied amendments resulted in an increase in peak standing crop only. Greatest yield of rillscale occurred on the fall-applied combination (gypsum, fertilizer, and sawdust) plot. These results were believed to occur because:

1. Fall amendments allowed some decomposition, natural mixing and aggregation of sawdust before seed germination; and
2. Infiltration rates and hydraulic conductivity of spoil increased after the addition of sawdust. A greater amount of winter precipitation was stored and available for plant use when amendments were applied in the fall.

3.4.6.3 Rates. There do not appear to be any generally agreed upon rates for application of wood waste to soils. The studies reviewed here indicate that the higher the rate, the better the response. It is critical, however, that nitrogen be added as well to prevent net nitrogen immobilization. Schuman and Belden (1991) and Allison et al. (1963) found that 5 to 13 kg nitrogen per tonne of wood waste is sufficient to supply enough nitrogen to prevent net N immobilization, thereby preventing any carbon to nitrogen ratio limitation to plant growth. A split application of nitrogen is likely more effective than a single large one. On sodic materials, gypsum may be required along with wood waste amendments.

3.4.6.4 Frequency. Application frequency will depend on purpose of the amendment, and will be limited mainly by the risk of ground and surface water pollution that will result when large amounts of nitrogen fertilizer are added concurrently.

3.4.7 Costs

A number of studies have examined the costs involved in using wood wastes as a soil amendment, but none has provided information for Alberta. For example, the cost of applying papermill sludge in Ohio in 1983 was found to be several times higher than applying the needed rates of lime, fertilizer and mulch (Vogel and Rothwell 1988). The differences were due to higher transportation costs for the sludge. However, yields of vegetation were found to be several times greater in spoils amended with sludge than with lime and fertilizer. Based on vegetation production, the cost-benefit ratio was found to be similar.

Costs for reclaiming a bentonite mine spoil in Wyoming in 1984 are presented in Table 45 (Richmond 1991). The greatest single cost item was the earthmoving at $6325.96/ha ($2565.00/acre). Total cost of reclamation was $10 435.16/ha ($4226.25/acre). Cost of amendments seemed high, but the alternative was to remove topsoil or other cover soil materials from offsite sources, creating offsite disturbances also requiring reclamation. In another abandoned bentonite surface mine study site in Wyoming, Richmond (1991) calculated that the cost of topsoil removed to cover the surface to a depth of 46 cm to prevent upward migration of Na into the rootzone would be $6214.81/ha ($2517.00/acre). Richmond (1991) calculated that a topsoil cover of 22.5 cm would cost $3444.44/ha ($1395.00/acre), compared to the cost of the amendment prescribed for this project (wood waste, calcium chloride, gypsum and lime) of $2676.54/ha ($1084.00/acre). Therefore, the use of amendments is an economically viable alternative if sources of topsoil are not available on the sites in the reclamation of bentonite mine spoils.

In Canada, costs for wood wastes vary depending on type of material, uses, and hauling distance. Ontario Environment (1991) notes that a typical sawmill in Ontario sells sawdust to farmers for animal bedding for about $100/11.34 m^3 load ($100/15 yd^3 load). No comparative figures could be found for Alberta.

Table 45. Reclamation costs using woodwaste on a bentonite mine in Wyoming.[a]

Activity	Unit Cost	Cost/Hectare	% of Total
Woodwaste procurement	[b]$ 13.74/Mg	$ 1311.73	12.6
Chisel Plowing	$185.19/ha	$ 185.19	1.8
Fertilizer	$370.37/ha	$ 370.37	3.5
Woodwaste application	$493.83/ha	$ 493.83	4.7
Woodwaste, fertilizer incorporation	$246.91/ha	$ 246.91	2.4
Seeding	$493.83/ha	$ 493.83	4.7
Earthmoving	$ 0.77/m^3	$6333.33	60.7
Other[c]	[d]N/A	$997.53	9.6
Total cost	N/A	$10432.72	100.0

[a] Source: adapted from Richmond (1991).
[b] All costs in 1991 U.S. dollars.
[c] Other includes mobilization, fencing and rock removal.
[d] Not applicable.

3.4.8 Longevity of Effects

Wood waste amendments may persist in the soil for a long time. Two studies in the United States indicated that only about 25% of applied wood waste had decomposed after 5 years, and that beneficial effects on plant growth were still obvious after 9 years.

Results of a study of the decomposition of wood waste amendments in revegetated bentonite mine spoils in Wyoming indicated that rate of decomposition was related to rate of nitrogen fertilization, not rate of amendment (Schuman and Belden 1991). Adequate soil moisture is also necessary.

Moore et al. (1991) studied revegetation on an abandoned bentonite mine spoil in Wyoming, amended with wood waste residue, nitrogen fertilizer, and gypsum. Effects on growth of perennial grasses were observed into the ninth year. The study concluded that high rates of wood waste (90 and 135 Mg/ha) may be required for long-term soil improvement and enhancement of plant growth. The persistence of wood waste benefits to spoils is generally attributed to slow decomposition (Schuman and Belden 1991).

3.4.9 Summary

3.4.9.1 Benefits. Wood wastes are relatively inert and slowly decomposable. Advantages of mixing them into soil include (Bollen and Glennie 1961):

1. Increased moisture retention;
2. Increased aeration;
3. Better tilth;
4. Reduced erosion;
5. Hindered weed emergence;
6. Reduced evaporation; and
7. Retain warmth, if the soil is not excessively wet.

As a mulch, wood waste materials are easier to apply, longer lasting, and less susceptible to blowing and fire than straw or leaves.

Benefits of woodwaste amendments are not permanent. Woowaste additions do not provide a permanent increase in soil organic matter. The establishment of plants on the soil in important for the long term maintenance of adequate soil organic matter levels. Growing plants provide an ongoing input of organic matter to the soil.

3.4.9.2 Drawbacks. Disadvantages of using sawdust and bark as mulches and as conditioners include (Bollen and Glennie 1961):

1. Competition with plants for available nitrogen;
2. Retention of excess moisture;
3. Retardation of temperature increases following cold periods;
4. Decreased pH if material is strongly fermented;
5. Packing of fine material; and
6. Objectionable features like slivers and dust.

Woodwastes are very slowly decomposable. As a result, woodwastes, will remain unaltered by soil organisms for a long time. Therefore, woodwastes are no as useful as some other materials for stimulating biological activity or for increasing nutrient cycling and availability. However, they still impart a desireable physical effect to the soil.

Although, nitrogen limitation is a problem, the slow decomposition of wood means that nitrogen can be gradually added over time.

3.4.10 Use for Reclamation

Reclamation of bentonite mine spoil is difficult due to several characteristics of the spoil, including high expanding clay content and high soluble salt (especially Na) content (Schuman and Sedbrook 1984, cited in Moore et al. 1991). These characteristics result in poor soil structure, low water infiltration, and high runoff potential. Topsoil was not salvaged during older mining operations and topsoil replacement from off site sources is often not economically or environmentally sound. Efforts to reclaim these soils have centred on applying organic and/or inorganic amendments to ameliorate adverse spoil characteristics (Moore et al. 1991; Schuman and Sedbrook 1984, cited in Moore et al. 1991; Smith et al. 1985, 1986; Voorhees and Uresk 1990).

Amendment of mine spoil with wood waste improves water infiltration and storage, leaches salts from the root zone, and enhances plant productivity (Belden et al. 1990). However, sodicity increases over time. Inorganic calcium amendments are necessary in combination with wood waste to obtain maximum plant growth (Moore et al. 1991).

Studies have found that high rates of wood waste (90 or 135 Mg/ha) may be required for long-term improvement of soil and enhancement of plant growth (Belden et al. 1990; Moore et al. 1991; Smith et al. 1985, 1986). Another study indicated that fall-applied wood waste amendments had a more positive effect on plant growth than spring applied amendments (Voorhees et al. 1987).

Since 1985, the Wyoming Abandoned Mine Land Program has reclaimed 3497 ha (8635 acres) of abandoned bentonite mines (Richmond 1991). The amendment program includes sawmill residues in combination with calcium compounds to mitigate clay and sodic problems. The long-term effectiveness of the wood waste and calcium has not yet been determined. In spite of the favourable costs and vegetative performances to date, use of these amendments as a substitute for available suitable soils is not recommended (Richmond 1991).

There are very few published data from Alberta on the use of wood wastes as a soil amendment. Alberta Research Council is beginning field research studies on the use of pulp and paper sludge as a soil amendment, but there are no results to date (T. Macyk Alberta Research Council, Edmonton, Alberta, pers. comm., 1992). The 1986 Directory of Primary Wood-Using Industries in Alberta lists 10 companies selling bark, sawdust, shavings, and softwood chips to farmers for cattle bedding. None reported distributing wastes as a soil conditioner or amendment (Bamsey 1987). However, as pointed out by Ontario Ministry of the Environment (1991), much of the wastes used as bedding will eventually be returned to the soil with manure.

3.4.11 Recommendations for Use in Alberta

1. 5 to 13 kg nitrogen per tonne of wood waste is sufficient to supply enough nitrogen to prevent net nitrogen immobilization. Split application of nitrogen, especially at higher rates are preferable, because nitrogen will be used efficiently resulting in less risk of contaminating groundwater.
2. Most studies to date indicate that the higher the rate of application of wood waste, the better the result. However, optimal rates and frequencies of application will be dependent on amounts of nitrogen fertilizer required, and purpose of the amendment.
3. Gypsum may be required in addition to wood wastes on sodic soil materials, to prevent increased SAR as soluble salts leach out of the root zone.

3.5 SEWAGE SLUDGE

This section deals primarily with municipal sewage sludges and their use as organic matter amendments. Discussion is restricted to sludges, because liquid effluents are not a good source of organic matter.

3.5.1 Types

In Alberta several different sewage treatment systems are in operation, including (Alberta Environment 1984):

1. Waste stabilization ponds (lagoons);
2. Aerated lagoons;
3. Primary treatment (settling) plants with lagoons; and
4. Secondary treatment plants.

Untreated sludge must be treated to make it suitable for land application. It must be thickened, dewatered, dried, and usually digested either anaerobically or aerobically. Digestion stabilizes degradable substances as biomass or converts them to CO_2 or CH_4. Through both aerobic and anaerobic digestion, most disease causing microorganisms are destroyed. Sludge from the bottom of lagoons is not normally treated prior to land application because the sludge has already been subjected to considerable biodegradation and reduction of disease causing organisms (Alberta Environment 1984).

Sewage sludge can also be composted to produce an environmentally safe, humus-like material that is odour and pathogen free (Parr et al. 1982). This compost can then be applied to land as a fertilizer and soil conditioner. The composting process is influenced by temperature, moisture, aeration, C:N ratio, pH, and particle size. Other chemical properties that can affect composting and product quality include soluble salts, toxic organic chemicals, sludge conditioning agents, and heavy metal content (Parr et al. 1982). Composting of sludge involves several steps. Further information on these steps can be found in Fryer (1986).

3.5.2 Sources

Some sewage sludge from cities and municipalities in Alberta is treated and used as a soil amendment. According to Alberta Environment (1984), Calgary injects about 185 000 m^3 annually to adjacent farmland. Edmonton applies about 150 000 m^3 of sludge annually to farmland. Both cities have sludge treatment plants and treat sludge by anaerobic digestion prior to land application. In addition, the City of Red Deer and the towns of Bentley, Taber and Claresholm have applied some form of sewage to farmland in the past.

According to Glen Brown (Goldbar Sewage Treatment Plant, Edmonton, Alberta, telephone conversation, January 5, 1993) there is plenty of sludge available in Edmonton, but hauling costs are high. The city has been applying sludge to farmland near the city since the late 1970's. About 20 000 Mg (dry weight) of sludge were produced in 1991, of which 14 000 Mg were disposed of on farmland. Application rates and soil suitability are monitored by Alberta Environment to prevent soil and groundwater pollution. No land can ever receive more than a lifetime addition of 47 Mg/ha in a total of 3 applications and there must be a resting period of 3 years between applications.

3.5.3 Chemistry

3.5.3.1 Chemistry of sewage sludge. Chemical characteristics typical of municipal sewage sludges in Alberta are presented in Table 46. Composition of sewage sludge varies between communities and reflects the nature of industry in the community and type of sewage treatment process used. Sewage sludges consist mainly of organic matter and water, but they also contain plant nutrients, salts, and metals (Alberta Environment 1984). Sludges have a high plant nutrient content compared to farm and chicken manure (Table 47).

Table 46. Typical composition of Alberta sewage sludges.[a]

	Composition of Alberta sludge as % dry weight[b] (unless otherwise noted)	
	Minimum	Maximum
Solids	1.0	20.0
Total Nitrogen	1.0	11.0
NH_4-Nitrogen	0.02	4.1
Total Phosphorus	0.25	2.3
Calcium	1.2	6.6
Magnesium	0.37	1.7
Sodium	0.002	3.4
Potassium	0.17	1.1
Iron	0.17	2.5
Manganese (ppm)	80	1000
Zinc (ppm)	390	1400
Copper (ppm)	280	1300
Lead (ppm)	50	1750
Nickel (ppm)	16	100
Cadmium (ppm)	4	20
Chromium (ppm)	22	1700
Boron (ppm)	7	33
Mercury (ppm)	1	6

[a] Source: Alberta Environment (1984).

[b] Sludge is dried to remove all water before analyses are done.

Table 47. Nutrient content (%) of digested sludge compared to average farm manure and chicken manure[a].

Nutrient	Sewage Sludge	Farm Manure	Chicken Manure
Total N	4.0	1.2	4.1
Total P	1.4	0.3	1.6
Potassium (K)	0.3	4.6	1.9

[a] Source: Adapted from original table in Alberta Environment (1984).

Sewage sludge is often composted to reduce total volume, make handling easier, and stabilize the product. Chemical properties for an anaerobically digested sewage sludge and a digested sludge compost are compared in Table 48. Composting sewage sludge results in material with a lower moisture content and a more stable nutrient content. One of the most noticeable differences between digested sewage sludge and digested sludge compost is in the relative concentrations of ammonium and nitrate. Ammonium concentration is much higher in the digested sewage sludge, whereas nitrate concentration is higher in the digested sludge compost. The C:N ratio for the dry digested sewage sludge was 10.3 and was 14.3 for the digested sludge compost, indicating a loss of total N during composting.

In the United Kingdom concentrations of Cd, Cu, Hg, Pb, Se, and Zn are much higher in sewage sludges than in soils (Table 49, Webber et al. 1984). Similar values and wide ranges for heavy metal concentrations for sewage sludges have been reported from the U.S.A. (Chaney 1989; Chang et al. 1989). Very high metal content often reflects sludge derived from industrial sources. When sludges are applied to soil, there is concern that concentrations of soluble metals in soil will also increase.

3.5.3.2 Effect of sewage sludge on soil chemistry. Studies dealing with sewage sludge application soil are summarized in Table 50.

3.5.3.2.1 Soil organic matter content. The proportional change in soil organic matter content following sludge addition is inversely proportional to the original soil C content, and rate of sludge decomposition upon addition to soil. For example, additions of 100 Mg of sludge (76% water;

Table 48. Composition of dry digested sewage sludge and digested sludge compost.[a]

Property	Sludge	Compost
pH	6.5	6.8
NH_4-N, ppm[b]	1200	190
NO_3-N, ppm[b]	3.5	140
Total N, %[b]	2.29	0.93
P, %[b]	2.18	0.16
K, %[b]	0.21	0.10
Ca, %[b]	1.84	1.98
Water, %	76	35
Organic C, %[b]	23.5	13.3

[a] Source: Epstein et al. (1976).

[b] Values based on oven dry sludge.

23.5% C (dry weight)) with 4% organic C (at a density of 0.5 g/cm^3) in the top 15 cm, yields on addition of 5.6 Mg of sludge C to 72 Mg of soil C. This would change soil C from 4% to 4.3%. Increases in soil organic carbon as a result of sludge applications would be limited, even at high loading rates. In a study on silt loam soils in Maryland, additions of either sludge or compost at 40 and 80 metric tons/ha did not result in measurable increases in soil organic carbon (Epstein et al. 1976). However, at levels of 160 and 240 Mg/ha, organic carbon was increased from 1.0% on the unamended soil to 1.5% and over 2.0% on 160 and 240 Mg/ha treatments.

3.5.3.2.2 Nitrogen and C:N ratio. Sewage sludge can provide a good source of nitrogen for plant growth. In Maryland, Epstein et al. (1976) found that total N on a silt loam soil amended with 160 and 240 Mg/ha sludge was significantly higher than on the unamended control or on treatments amended with only 40 or 80 Mg/ha sludge, even two years after being applied. In the same study, C:N ratios were reduced with the addition of both sewage sludge and sewage compost.

King (1973) concluded that net N mineralization rates should determine sludge application rates such that the sludge supplies adequate N for crop production, but insufficient to

Table 49. Range of heavy metal concentrations (mg/kg dry wt.) in United Kingdom sewage sludges and agricultural soils.[a]

Element	Sludge		Soil		Ratio
	Range	Common Value	Range	Common Value	Sludge/ Soil
Arsenic	3 to 30	20	1 to 50	6	3
Boron	15 to 1000	30	2 to 100	10	3
Cadmium	2 to 1500	20	0.01 to 2.4	1	20
Cobalt	2 to 260	15	1 to 40	10	1.5
Chromium	40 to 14 000	400	5 to 1000	100	4
Copper	200 to 8000	650	2 to 100	20	32
Fluorine	60 to 40 000	250	30 to 300	150	2
Mercury	0.2 to 18	5	0.01 to 0.3	0.03	167
Molybdenum	1 to 40	6	0.2 to 5	2	3
Nickel	20 to 5300	100	10 to 1000	50	2
Lead	50 to 3600	400	2 to 200	20	20
Selenium	1 to 10	3	0.01 to 2	0.2	15
Zinc	600 to 20 000	1500	10 to 300	50	30

[a] Source: Webber et al. (1984).

Table 50. Summary of studies on the effects of sewage sludge application on the chemical properties of soils.

Reference	Location and soil	Duration of study	Type of sludge	Rates applied	Effects on Soil			
					pH	Organic Matter	Nutrients	Salinity
Epstein et al. (1976)	Maryland, silt loam	2 years	Digested and Composted	0, 40, 80, 160, 240 Mg/ha, surface applied and rototilled	Decreased by less than 1 unit	Increased at rates greater than 160 Mg/ha.	Increased CEC, higher increases for sludge compared to compost, but began to decrease after 2 years. Total N increased, all rates. C:N ratios decreased. Increased P with increasing rates of sludge and compost.	Increased as rate of sludge or compost increased.
Darmody et al. (1983)	Maryland, silt loam	3 years	Composted	0, 336 and 672 dry Mg/ha (0, 150 and 300 tons/ac), surface applied and rototilled			Increased levels of Ca, P, and K for 3 years of study.	
Guidi and Hall (1984)	Various	Literature review	Various	Various	Increased on acidic soils, decreased on soils with higher pH.		Limited increases even at high rates because level of organic matter in sludge is relatively low.	
Tester (1990)	Maryland, loamy sand	5 years	Composted	Single application of 0, 60, 120, 240 Mg/ha and annual applications of 33, 67, 134, and 268 Mg/ha, surface applied and rototilled		Increased.		
King (1973)	Georgia, sandy loam	Laboratory experiment	Digested	6.3 cm, incorporated or surface spread			More accumulated N after incorporation than after surface application.	
Mills and Zwarich (1982)	Manitoba, fine-textured lacustrine	6 years	Digested	0, 210, 360, 470 dry Mg/ha surface spread			Increased N levels for several years, before leaching through soil.	

cause nitrate pollution of groundwater. She found that incorporated sludge treatments resulted in greater accumulation of nitrate and lower gaseous losses compared to surface applied treatments.

In a study to determine the accumulation, movement, and losses of nitrate over a period of 6 years on a poorly drained, fine-textured soil in Manitoba, heavy rates of 210, 360 and 470 dry Mg/ha sewage sludge were applied to the soil surface (Mills and Zwarich 1982). These authors found that high rates of sludge applications resulted in nitrate accumulations and that risk of groundwater contamination would be greater for permeable soils with good drainage.

3.5.3.2.3 Other nutrients and nutrient status. Other nutrient concentrations in soil can be affected by the addition of sewage sludge. For example, amount of available P increases with additions of sewage sludge and sewage compost (for example Darmody et al. 1983; Epstein et al. 1976). Darmody et al. (1983) also noted higher concentrations of extractable K and Ca with addition of composted sewage sludge.

Cation exchange capacity (CEC) of the soil can be increased by sewage sludge or sludge compost additions (Epstein et al. 1976) Increases in CEC was greater when sludge was applied to the soil compared to sludge compost. Two years after the additions, CEC began to decrease.

3.5.3.2.4 pH. The relative availability of some nutrients and toxic metals is pH dependent; with many being more soluble at lower pH. Guidi and Hall (1984) reported that the change in soil pH following sludge addition depended on the initial soil pH. Decreased pH occurred when organic acids were produced during decomposition and nitrification. Increased pH occurred when the initial soil pH was low and the sludge had been treated with lime. Epstein et al. (1976) found that pH decreased less than one unit two years following sludge or compost additions to a silt loam in Maryland. Even a decrease in pH of this small magnitude was considered important because metals are generally more available to plants at lower pH.

3.5.3.2.5 Salinity. Increased salinity in silt loam soils after additions of sewage sludge and sludge compost in Maryland was found by Epstein et al. (1976). Electrical conductivity (EC) increased with additions of sludge and sludge compost. EC values were higher with sludge than with sludge compost. At compost rates of 160 and 240 Mg/ha and sludge rates of 80 Mg/ha or greater, the increase in EC was great enough to affect germination and growth of salinity sensitive crops. However, by the end of the first growing season, EC values were considerably lowered due to leaching. In drier climates such as in Alberta, leaching would not likely occur as quickly, nor should leaching be deemed an appropriate way to deal with salts from sludges. Passing the salt on to groundwater is only a transfer of the problem, not a solution.

3.5.3.2.6 Heavy metals. Uptake of heavy metals by plants is influenced by soil pH, organic matter content, and CEC (Alberta Environment 1982), as well as by the species and variety of plant. The United States Environmental Protection Agency (1976, cited in Alberta Environment 1982) divides heavy elements into two groups based on their potential hazard to plants and animals when added to soil in sewage sludges. Mn, Fe, Al, Cr, As, Se, An, Pb and Hg pose relatively little hazard. Some of these elements form stable organic or inorganic complexes, while others are present in low quantities at the sludge rates designed to meet nitrogen requirements of crops (Alberta Environment 1982). Cd, Cu, Mo, Ni and Zn on the other hand, can pose significant hazards; Cd is considered be the major hazard. The long-term use of sewage sludge on agricultural land is limited by the potential heavy metal accumulation.

Results of studies on heavy metals in soils are presented in Table 51. Although results are variable, it is generally considered that heavy metals in sewage amendments can pose a hazard, particularly with repeated applications. In order to minimize heavy metal contamination, guidelines have been set up for the utilization of sludges in Alberta (Alberta Environment 1982). However, Halderson and Zenz (1978) reported that unless soil has abnormally high metal levels or low pH (<6.5), phytotoxicity is not a significant cause for concern. Younos (1987), in a review of several studies, found that decreases in trace metal concentrations in sludge-grown vegetation occurred over several years when a single application of sludge was used. Sludge-grown vegetation usually contained higher heavy metal (Cu, Zn, Cr, Pb, Cd and Ni) concentrations than plants grown in soils without added sludge, but in most cases, the heavy metal concentrations were not a threat to human or animal health.

3.5.4 Physical Properties

3.5.4.1 Physical properties of sewage sludge. The literature provides little information on the physical properties of sewage sludge or composted sludge material. In Alberta, sludge is applied to soil in a liquid or slurry form. If sludge is composted, usually with a bulking agent such as wood chips, the product is similar to other types of compost.

Table 51. Summary of research on the effects of sewage additions on heavy metals in soil.

Reference	Location and Soil Type	Type of Sludge	Rates	Duration	Crop	Effects on Soil
Tackett and Yadvish (1987)	Pennsylvania, silt loam strip mined site	Composted mix	128 Mg/ha (57 tons/ac) incorporated into limed site	1 year	hay	Increased Pb, Cu, and Zn
Soon and Bates (1985)	Ontario loam and sandy loam	Various sludges digested	Various rates to give 1600 kg N/ha	not known	corn and bromegrass	No problems posed from B, Co or Mo
Logan et al. (1987)	California sandy loam and silt loam	Composted	0, 22.5, 45, 90 and 180 Mg/ha annually	8 years	barley, swiss chard, lettuce	Increased Se from <0.1 mg/kg to 1.2 mg/kg in surface 0 to 15 cm soil. No significant increase in plant Se concentration
Dudas and Pawluk (1975)	Alberta, greenhouse study on clay loam and loam soils	Digested	80 and 160 Mg/ha	pot study	lettuce	Increased plant Zn, Cd, Sr, Cu. No increase in plant Pb and Hg. Poor plant growth at 160 Mg/ha
Dressler et al. (1986)	Pennsylvania, mined land	Composted sludge mix	134 Mg/ha incorporated into surface 10 cm	1 year	bromegrass, orchardgrass, tall fescue, trefoil	No difference in heavy metals between control and sludge treated 0 to 15 cm soil. Increased Zn for all plant varieties; increased Cu and Cd for 3 of 4 varieties

3.5.4.2 Effect of sewage sludge on soil physical properties. Studies on the effect of sewage sludge on soil physical properties are summarized in Table 52.

3.5.4.2.1 Soil bulk density. A number of studies report a decrease in soil bulk density with increasing rates of sewage sludge or sewage compost addition (Darmody et al. 1983; Guidi and Hall 1984; Joost et al. 1987; Tester 1990). Tester (1990) also reported reduced penetration resistance with increasing rates of sewage application.

3.5.4.2.2 Soil porosity. Addition of sewage sludge generally appears to increase soil porosity. However, low rates of sludge application (12.5 to 37.5 Mg/ha) were not sufficient to increased porosity (Guidi and Hall 1984).

3.5.4.2.3 Soil moisture characteristics. Application of sewage sludge and sludge compost to soils tends to increase moisture content. Epstein et al. (1976) found that moisture content for sludge- and sludge compost-amended silt loam soils in Maryland was higher than for a control. Soil moisture was higher on the sludge-amended treatments than on the compost treatments. Similar results were reported by Guidi and Hall (1984), in their literature review. Increases in soil moisture were greater for coarse-textured soil than for fine-textured soil.

3.5.5 Biological Properties

3.5.5.1 Biology of sewage sludge. Many human pathogens are found in sewage sludge, including bacteria, viruses, fungi, helminths (worms), protozoa, and fungi (Younos 1987). Pathogens remain viable in sludge for varying periods of time. Viruses appear to be the most resistant. Thus there is potential for spreading of infectious diseases through land applications of sewage sludge. However, to date, no studies have found a correlation of land applications of sludge to occurrences of infectious or parasitic diseases (Younos 1987).

Factors that affect the survival of bacteria, viruses, helminths, and protozoa in sewage sludge include (Younos 1987):

1. Temperature (as a rule high temperatures are more effective in destroying bacteria);
2. pH (as a rule, bacteria survive better in neutral or alkaline soils);

Table 52. Summary of studies on the effects of sewage sludge application on the physical properties of soils.

Reference	Location and soil	Duration of study	Rates applied	Bulk density	Soil moisture
Darmody et al. (1983)	Maryland	4 years	0, 150 and 300 Mg/ha	Decreased from 1.30 g/cm^3 on 0 Mg/ha treatment to 1.06 g/cm^3 on 300 Mg/ha treatment	
Joost et al. (1987)	Illinois mine spoil	2 years	0, 225, 450, and 900 Mg/ha	Decreased from 1.44 g/cm^3 on 0 Mg/ha treatment to 0.99 g/cm^3 on 900 Mg/ha treatment	
Tester (1990)	Maryland, loamy sand	5 years	single applications of 0, 60, 120 and 240 Mg/ha and annual applications of 33, 67, 134 and 268 Mg/ha, surface applied and rototilled	Decreased 45% on 240 Mg/ha treatment; decreased with increasing annual additions, 1.13 g/cm^3 on 33 Mg/ha treatment and 0.66 g/cm^3 on 268 Mg/ha treatment	
Guidi and Hall (1984)	Various	Literature review	Various	Decreased with incresaing content of sludge organic matter on sandy and loamy soil	Increased water holding capacity with increasing rate of sludge organic matter, increases were greater for coarse-textured soil than for fine-textured soil
Epstein et al. (1976)	Maryland	2 years	0, 40, 80, 160, 240 Mg/ha		Soil moisture content 20% greater than control on sludge treatment and 5% to 10% greater than control on compost treatment

3. Sunlight (ultra violet radiation can destroy some bacteria at the soil surface);
4. Moisture content (greater moisture increases survival);
5. Soil type;
6. Organic matter; and
7. Presence of other microorganisms (competition and predation).

Disinfection of sewage sludge is desirable especially if land application is being considered. Disinfection minimizes the possibility of pathogens being transmitted. Pathogens can be reduced below detectable levels by several processes, including (Alberta Environment 1982; Havelaar 1984):

1. Pasteurization;
2. Irradiation (high energy radiation disinfection);
3. High pH (lime) treatment;
4. Long-term storage;
5. Complete composting at high temperature (>55°C); and
6. Chemical disinfection.

Lack of an effective sterilization process has hampered the expansion of land disposal of sewage sludges in Alberta (G. Brown, Goldbar Sewage Treatment Plant, Edmonton, Alberta, telephone conversation, January 5, 1993). Unless the material is pathogen-free, it cannot be registered by Alberta Agriculture, and sold as a fertilizer. At present, the City of Edmonton must pay for all land disposal costs, including hauling and spreading. If the material could be sold, a larger proportion of the city's output of sewage could be disposed of by land application. The City of Edmonton is currently examining various options to sterilize sewage, including irradiation and lime application (McKeen 1993).

3.5.5.2 Nature of effect on soil biology. Potential health problems caused by disposal on land of sewage sludge containing pathogens was studied by Lehmann et al. (1983) near Crossfield, Alberta. Pathogens were reduced but not eliminated through anaerobic digestion, lagoon storage, and land application. Viruses were not present in lagoon sludge, sludged fields, or non-sludged field and pasture controls.

Most organisms found in sewage sludge are innocuous or are beneficial to the soil. Pathogens are not the only organisms in soil: others benefit both the crop and soil. Five coal mine surface sites reclaimed with sewage sludge and one site reclaimed using chemical fertilizer were studied in Pennsylvania to determine the effects of sewage sludge applications on microbial populations and activity (Seaker and Sopper 1988). Populations of aerobic heterotrophic bacteria, fungi, and *Nitrobacter* (nitrifying bacteria) were highest on the 1-year old sites amended with sewage. Populations decreased for older sites. Sludge-amended plots had larger populations than the fertilized treatment. *Nitrosomonas* (nitrifying bacteria) populations on sludge-amended plots were not related to the age of sludge sites, and were higher than on fertilized plots. Actinomycete populations were highest on the 3 and 4 year old sites, and sludge-amended plots had higher populations than the fertilized treatment. An initial flush of bacteria and fungi occurred immediately following sludge applications; Actinomycetes are less competitive than bacteria and fungi (Alexander 1977) and respond later when competition has decreased (Seaker and Sopper 1988).

3.5.6 Application

Application of sewage sludge in Alberta is limited to lands used for the production of forages, oil seeds, small grains, trees and commercial sods (Alberta Environment 1982). Sludge should not be applied on lands used for the production of crops that may be eaten raw.

3.5.6.1 Methods. Sewage sludge can be applied to the soil by surface spreading or by injection into the top layer of the soil (Alberta Environment 1984; Godwin et al. 1985). Injection of sewage sludge below the soil surface helps eliminate odours and can control surface run-off, pathogen transfer, and crop taint (Godwin et al. 1985). However, this method is more expensive than surface spreading.

3.5.6.2 Timing. Fall appears to be the best time to apply sewage sludge. A survey indicated that farmers generally prefer to apply sludge in the fall or in the winter (Webber et al. 1990). Alberta Environment (1982) specifies that sewage sludge must be applied under conditions which will permit injection or surface application, preferably with immediate incorporation. Applications to frozen soil are not permitted because there is a high probability of runoff. The City of Edmonton spreads sludge on surrounding farmland in the 3 to 4 weeks after spring breakup and before seeding, and in the 6 to 8 weeks after fall harvest but before winter freeze up.

3.5.6.3 Rates. Alberta Environment (1982) has set guidelines for the use of municipal wastewater sludges on agricultural lands. Sludges are classed as digested, waste-stabilized lagoon, and undigested. Sludges must exceed the acceptable nitrogen or phosphorous to metal ratios given in Table 53. Sites proposed for sewage sludge applications are classified into four groups based on soil characteristics, topography, and geology (Table 54). Class 1 sites are the most suitable for sludge applications, whereas Class 4 sites are not acceptable.

Table 53. Minimum acceptable ratios of nitrogen and phosphorus to metals and boron in sludge to be applied to land.[a]

	Cd	Cr	Cu	Hg	Ni	Pb	Zn	B
Nitrogen[b]	1500[c]	20	15	3000	100	20	10	300
or[d]								
Phosphorus	600	8	6	1100	40	8	4	120

[a] Source: Alberta Environment (1982).

[b] Organic + Nitrate + Ammonium.

[c] N/Cd = 1500.

[d] Sludge is acceptable if either the nitrogen or phosphorus criterion is met. Spiking sludges with nitrogen or phosphorus to achieve these ratios is not permitted.

The amount of sludge solids and sludge-borne nitrogen that can be applied to soil in a single application for each sludge and site class are presented in Table 55. The maximum cumulative additions of sludge-borne heavy metals for each site class are shown in Table 56. These guidelines were formulated to prevent heavy metal pollution of the foodchain, water sources, soils and crops. Additional restrictions on application of sewage sludge include methods of acceptable application, minimum distances from specified features (water courses, wells, dugouts, occupied buildings, public buildings and their boundaries, and other public areas), timing of application, acceptable and unacceptable crops for application, and application to previously amended sites. It is recommended that the Alberta Environment publication "Guidelines for the Application of Municipal Wastewater Sludges to Agricultural Lands" be consulted before applying sewage to any site.

Similar sets of guidelines for sewage sludge use for land reclamation have been established by the U.S. Environmental Protection Agency and the Pennsylvania Department of Environmental Resources (Dressler et al. 1986).

Table 54. Classification of sites for sludge additions on the basis of soil characteristics, topography and geology.[a]

	Acceptable[b]			Not Acceptable
	Class 1 Sites	Class 2 Sites	Class 3 Sites	Class 4 Sites
pH	$\geq$6.5	$\geq$6.5	$\geq$6.5	<6.5[c]
Texture[d]	CL, SiCL, SiL, Si, SiC, L, SCL, SC	C, HC	LS, SL	Sand and gravel[e]
Slope[f] %	0 to 2	2 to 5	5 to 9	9
Depth to Potable Aquifer (m)	>5	3 to 5	2 to 3	<2

[a] Source: Alberta Environment (1982).

[b] A site falls into the lowest class represented by any characteristic.

[c] A site with pH less than 6.5, which would otherwise be classed 1 or 2 may be upgraded by liming to pH 6.5 or higher.

[d] As determined on samples from representative soil horizons to a depth of at least 30 cm.

[e] Other class 4 sites include stream valleys, intermittent drainage areas and organic soils.

[f] Restriction of sludge application rates based on slope apply only when surface application methods are employed. Slope criteria can be relaxed if sludge is applied by subsurface injection.

Table 55. Maximum addition of sludge solids and sludge-borne nitrogen to soil for each site class and sludge type - single application.[a]

Sludge Type	Solids Application Rate[b] Mg/ha dry weight basis			Total N Application Rate kg/ha			Available N[c] Application rate for surface spreading[d] kg/ha		
	Class 1 Sites	Class 2 Sites	Class 3 Sites	Class 1 Sites	Class 2 Sites	Class 3 Sites	Class 1 Sites	Class 2 Sites	Class 3 Sites
Digested	25	20	10	900	700	400	450	350	200
Waste Stabilization Pond	10	8	5	800	600	300	400	300	150
Undigested[e]	5	4	2.5	600	500	20	300	250	100

[a] Source: Alberta Environment (1982).

[b] For surface application a maximum hydraulic loading of 100 m^3/ha/day is imposed for sludges containing less than 5% solids. Allowable solids and N rates for such sludges may be achieved by making several incremental additions with the soil cultivated between each addition. There is no hydraulic loading rate restriction on sub-surface injection.

[c] Available N = (NH_4 + $N0_3$).

[d] For sub-surface injection the maximum available N application rate is 200 kg/ha on Class 1 and 2 sites and 150 kg/ha on Class 3 sites.

[e] Undigested sludge must have been stored for a minimum of 6 months, have a pH of greater than 12 or have a volatile solids content of less than 60% of the total weight of solids.

Table 56. Maximum permissable cumulative additions of sludge-borne elements to soils [a,b] (kg/ha).

	B[c]	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Class 1 Sites	10	1.5	100	200	0.5	25	100	300
Class 2 Sites	7.5	1.1	75	150	0.4	19	75	200
Class 3 Sites	5	0.8	50	100	0.2	12	50	150

[a] Source: Alberta Environment (1982).

[b] Not more than 1/3 of the cumulative loading may be applied in a single application.

[c] Boron levels are hot-water soluble. Levels for other elements are based on total quantities.

3.5.6.4 Frequency. Alberta Environment (1982) indicates that, provided maximum cumulative elemental additions have not been equalled or exceeded (Table 56), agricultural sites previously treated with sewage sludge can be treated again after 3 years. However, available nitrogen content must be less than 250 kg/ha for the top 150 cm of soil.

3.5.6.5 Equipment. Equipment and facilities required to store sludge and apply it to soil include (Alberta Environment 1984):

1. Storage facilities;
2. Tank trucks to haul sludge from source to field;
3. Field equipment to work surface-applied sludge into the soil; and
4. Spreading or injection equipment.

3.5.7 Costs

There is no charge for sludge from the City of Edmonton. Because the material is not guaranteed pathogen-free, it cannot be registered as a fertilizer under Alberta Agriculture regulation. At present, Edmonton pays on average about $60 per tonne for disposal of all sludge. A similar program in Calgary is even more costly (G. Brown, Goldbar Sewage Treatment Plant, Edmonton, Alberta, telephone conversation, January 5, 1993).

3.5.8 Longevity of Effects

Few studies exceeded 5 years. In Maryland, Tester (1990) found that 24% of the sludge compost that had been added decomposed during the first year; during the next 3 years, 28% of the residual material decomposed. In another study on coal mine spoil in Illinois, Pietz et al. (1989b) found that concentrations of nitrate peaked after 3 years, but decreased to near background concentrations within 5 years. Phosphorus concentrations also declined over time, but K concentrations remained constant throughout the experiment.

The effect of sludge on soil organic matter concentrations and on nutrient supplying power is expected to be similar to that of animal manures, due to the similarity of the materials. The survival of human pathogens is not expected to be long-term because these organisms are not suited to living in the relatively cold and competitive soil environment. The greatest long-term effect of sludge amendment on soils would be the increased concentrations of heavy metals which would not decline appreciably over time.

3.5.9 Summary

3.5.9.1 Benefits. Benefits of using sewage sludge for land application include (Alberta Environment 1984):

1. Increased crop production;
2. Reduction in fertilizer costs;
3. Recycling of nutrients;
4. Soil conditioning;
5. Simple disposal of municipal wastes; and
6. Environmental acceptability if guidelines are followed.

Benefits of sewage sludge amendments are not permanent. Sewage sludge additions do not provide a permanent increase in soil organic matter. The establishment of plants on the soil is important for the long term maintenance of adequate soil organic matter levels. Growing plants provide an ongoing input of organic matter to the soil.

3.5.9.2 Drawbacks. Drawbacks to using sewage sludge for land application include (Alberta Environment 1984):

1. Potential health hazards unless sterilized or incorporated immediately;
2. Potential adverse effects on soil and groundwater if guidelines are not carefully followed;
3. Potential for undesirable odours and aesthetic problems near populated areas; and
4. Some land cropping restrictions (ie. edible root crops).

3.5.10 Use for Reclamation

3.5.10.1 Coal mine reclamation. Most reports are from studies on acidic spoils from mines in Eastern and Central United States (Table 57). In such sites, lime or some other material must be added to raise soil pH to near neutrality, thereby preventing the mobilization of heavy metals that would take place under an acidic soil regime. Much less work has been carried out on the usually alkaline, saline and sodic mine spoils of the Northern Great Plains. No examples of the use of sewage sludge for the reclamation of mine spoils in Alberta were found.

Table 57. Summary of research on the use of sewage sludge on coal mine spoils.

Reference	Location	Type of Sludge	Rates Applied	Duration	Results
Pietz et al. (1989a,b,c)	Illinois	Anaerobic digested	542 Mg/ha sludge + 89.6 Mg/ha lime, disced to 20 cm depth.	5 years	Sewage sludge + lime not effective in maintaining spoil pH, and reducing water soluble Fe, Al, and total acidity. Increased NH_4 and NO_3-N, P, and K. NH_4-N, NO_3-N and P found in percolate water.
Joost et al. (1987)	Illinois	Dried sewage sludge	225, 450 and 900 Mg/ha sewage sludge incorporated to 30 or 60 cm depths, + 45, 90 and 180 Mg/ha lime.	4 years	Decreased bulk density. Increased soil pH compared to unamended spoil. No accumulation of heavy metals in plant tissues.
Seaker and Sopper (1988)	Pennsylvania	Combination of composted and uncomposted sewage sludge.	120 to 134 Mg/ha sewage sludge, after adding lime to bring soil pH to 7.0.	5 years	Increased bacteria, fungi, nitrobacter and actinomycetes. Increased dry matter plant yields. Increased soil organic matter content, with site age. N remained high after 5 years.
Peterson and Gschwind (1972)	Illinois (lab and field study)	Liquid digested sludge.	448 to 560 dry Mg/ha incorporated.	Unknown	Decreased Al concentration, Increased soil fertility. Increased water holding capacity. Improved tilth.
Skousen (1988)	West Virginia	Anaerobic municipal sewage sludge.	0, 22.4, 44.8, and 78.4 Mg/ha, not incorporated, lime added.	2 years	Increased vegetation growth. Increased heavy metals in soil, but did not affect vegetation or move into surface water supplies.
Sopper and Kardos (1972)	Pennsylvania	Sewage effluent and sludge.	Various rates, effluent + sludge.	3 years	Increased vegetation growth. Increased soil pH. Increased P + NO_3-N in percolate. Decreased Mn, Fe, Al in percolate.
Topper and Sabey (1986)	Colorado	Aerobically digested municipal sewage sludge.	0, 14, 28, 55, and 83 Mg/ha dry sewage sludge, incorporated with one pass with chisel plow.	2 years	Increased vegetation at levels $<$ 83 Mg/ha. Increased heavy metal loading. Increased EC, N, P, and K. Decreased pH. Increased soil organic matter and water holding capacity.

continued...

Table 57. Concluded.

Reference	Location	Type of Sludge	Rates Applied	Duration	Results
Roberts et al. (1988)	West Virginia	Anaerobically digested	0, 22, 56, 112, and 224 Mg/ha, surface applied.	5 years	Increased vegetation growth, N and P. No problem with heavy metal uptake in plants, even at highest rates of application.
Stucky and Zoeller (1980)	Illinois (greenhouse study)	Anaerobically digested	0, 224, 336, and 448 Mg/ha.	1 year	Increased pH, soil organic matter, CEC, EC and plant yields.

Advantages of applying sewage sludge to coal mine spoils are:

1. Improved vegetation growth;
2. Improved soil structure;
3. Decreased bulk density;
4. Improved nutrient status;
5. Improved long-term fertility;
6. Increased organic matter content; and
7. Increased water holding capacity.

A continuing concern that arises is that heavy metals in sewage sludge may be available for plant uptake. Also, when sewage sludge is applied to acidic soil, increased solubilization of heavy metals could result in ground or surface water contamination.

Some of the major effects of coal mine spoil reclamation with sewage sludge can be summarized in research by Pietz et al. (1989a, b, c). These studies determined the effects of sewage sludge, lime, or gypsum; and various combinations of these amendments on the chemical composition, revegetation and percolate water composition of coal refuse material in Illinois. They concluded that sewage sludge in combination with lime was effective in establishing vegetation because of its ability to supply nitrogen, phosphorus, and potassium to plants. Ammonium, nitrate and phosphorus increased in percolating water, but these levels declined over time and approached background values after 5 years (Pietz et al. 1989c). Concentration of metals in percolate waters was pH dependent; as pH declined, metals were solubilized. Combined sludge and lime treatments were effective in reducing metal leaching when the pH of the percolate water was maintained ≥ 5.0.

Joost et al. (1987) investigated availability for plant uptake of heavy metals such as Cd, Cr, Pb, and Ni when sewage sludge was applied to coal mine spoil in Illinois After sludge additions, although levels of these heavy metals were present in the soil at levels considered to be toxic to plants, the heavy metals had not accumulated in plant (grasses) tissues.

Some elements were found to be strongly bound to soil or retained in plant roots and, even when present in soil at high levels, were not taken up by plant foliage (Chaney 1989). These elements include Fe, Pb, Hg, Al, Ti, Cr^{3+}, Ag, Au, Si and Zr. Some elements, such as Zn, Cd, Mn, Mo, Se and B were found to be easily absorbed by plants, but phytotoxicity may limit plant levels of some of these elements to concentrations that are safe for animals. Chaney (1989) also indicated that interactions of metals in sludge may reduce or increase predicted availability or toxicity compared to single metal salt studies.

Applications of sewage sludge on coal mine spoil have been found to increase soil organic matter and water holding capacity. For example, Joost et al. (1987) and Seaker and Sopper (1988) report organic matter of sludge-treated mine spoil increased compared to unamended plots. Water holding capacity of a Colorado mine spoil increased as a result of increased organic matter (Topper and Sabey 1986).

3.5.10.2 Borrow pits and calcareous subsoil. Generally, borrow pits have had both the A and B horizons removed, exposing the subsoil. The subsoil is often compacted, eroded, and impervious to root growth (Berry and Marx 1980). Other characteristics of borrow pits include low available water, low fertility, and low organic matter. Ameliorative effects of the application of sewage sludge to these sites include increased vegetative growth, increased fertility, increased organic matter, decreased bulk density, and increased available water capacity (Table 58).

3.5.10.3 Iron-mine tailings. Studies dealing with reclamation of iron-mine tailings are presented in Table 58. Characteristics of iron-mine tailings can include nitrogen and phosphorus deficiencies, low water holding capacity, high heavy metal content, and poor temperature regimes (Borgegård and Rydin 1989; Wong and Lai 1982). Ameliorative effects of sewage sludge amendments are similar to those reported for coal mine spoils, including increased vegetation, increased water holding capacity, and improved nutrient status.

3.5.10.4 Final landfill cover. Final cover material for a landfill site in Oregon was difficult to revegetate because of poor physical and chemical properties (Wilson et al. 1985). The final cover had poor structure and was low in organic matter and nutrients. Additions of sewage sludge, in excess of normal agricultural rates were made to establish vegetation and stabilize cover material by protecting it from water erosion. The amendments resulted in increased vegetation and improved nutrient status. Crop quality was not reduced by heavy metal uptake.

3.5.10.5 Degraded semiarid grassland. Sewage sludge was applied to a degraded semiarid grassland in New Mexico at rates of 22.5 to 90 Mg/ha (Fresquez et al. 1990). This site was low in organic matter and plant available nitrogen, and had been subjected to severe water erosion.

Table 58. Summary of research on the use of sewage sludge for reclamation on sites other than coal mines.

Reference	Location	Type of Disturbance	Type of Sludge	Rate	Duration	Results
Berry and Marx (1980)	South Carolina	Borrow pit	Anaerobically digested	1.3 cm deep, incorporated	3 years	Increased N, P, organic matter, CEC, vegetation growth.
Berry (1985)	Georgia	Borrow pit	Anaerobically digested	17 Mg/ha + subsoiling and discing treatments, incorporated to 15 cm.	3 years	Increased N, P, Mn, Zn, Cu. Subsoiling resulted in better growth than discing treatments.
Loebel et al. (1982)	Ontario	Calcareous subsoil roadside waste	Partially composted sewage sludge-leaf mixture.	0, 125, and 250 Mg/ha, incorporated to 15 cm.	1 year	Increased organic matter, CEC, NH_4, NO_3, P, vegetation growth. Decreased bulk density Increased available water holding capacity. Increases in B, Zn, and Cd in poplar tissues, no increases in trefoil tissues.
Borgegard and Rydin (1989)	Sweden	Iron mine tailings	Sewage sludge and bark mix	10 cm layer plus NPK fertilizer	2 years	Increased vegetation growth, NO_3, and water holding capacity.
Wong and Lai (1982)	Hong Kong (greenhouse study)	Iron-mine tailings	Activated sludge	0, 16.7, and 33.3 Mg/ha.	Unknown	Increased vegetation, alkaline pH of the tailings contributed to low availability of heavy metals.
Wilson et al. (1985)	Oregon	Final landfill cover	Wastewater sludge	67.3 and 134.5 Mg/ha incorporated to 10 cm.	Unknown	Increased vegetation growth. Crop quality not affected by heavy metal uptake.
Fresquez et al. (1990)	New Mexico	Degraded semi-arid grassland	Anaerobically digested	0, 22.5 45, and 90 Mg/ha, surface applied.	4 years	Increased N, P, K, EC, and soil organic matter. Decreased pH. Increased Cu, Fe, Mn, Zn, Cd, and Pb, but below phytotoxic levels. After 4 years, Cu, Mn, Cd slightly above acceptable soil standards at high levels of sewage sludge.

Although the site was not an industrial disturbance, conditions were likely similar to those at reclamation sites in which adequate topsoil salvage and replacement had not taken place. Macronutrients (N, P, and K), EC, and soil organic matter increased with sludge treatments, whereas pH decreased. Soluble Cu, Fe, Mn, Zn, Pb, and Cd increased with additions of sewage sludge, most likely as a result of decreasing pH. Although far below phytotoxic levels, concentrations of Cu, Mn, and Cd were slightly above established soil standards for the 90 Mg/ha treatment. The authors concluded that there were no adverse environmental effects at sludge rates up to 45.0 Mg/ha.

3.5.11 Recommendations for Use in Alberta

The following recommendations can be made for the use of sewage sludge and sewage compost as a soil amendment for reclamation in Alberta:

1. Sewage sludge in most of its forms is suitable for use as a soil amendment for reclamation in Alberta. Most cities, towns, and villages throughout the province have sources that are not currently being utilized.
2. The extent of problems of pathogens in the material where used for reclamation must be determined, and then resolved before it can be widely used in the province.
3. The use of sewage sludge in Alberta is closely regulated by Alberta Environment. Guidelines outlined in Alberta Environment (1982) "Guidelines for the Application of Municipal Wastewater Sludges to Agricultural Lands" must be closely followed.

3.6 MUNICIPAL AND YARD COMPOST

This section deals specifically with the composting of municipal solid waste (garbage) and yard wastes. Uncomposted yard wastes, which can also be directly applied to the soil (Hegberg et al. 1990) will be discussed in this section as well. Composting of other materials such as manure, peat, wood waste, straw, and sewage sludge is dealt with in the sections for those materials.

Composting has been defined as a controlled aerobic biological process designed to decompose and stabilize the organic fraction of solid waste material (Ontario Ministry of the Environment 1991; Senesi 1989). The organic fraction of landfills constitutes around 65% of total municipal solid waste (Epstein and Engel 1991). As many communities are restricting landfill developments due to groundwater concerns and lack of space, composting is becoming more popular. Composting can divert organic material from landfills and put it to productive use.

3.6.1 Types

There are two types of systems used to prepare compost:

1. Slow or natural decomposition, where materials to be composted are piled or windrowed; and
2. Accelerated decomposition carried out in digesters or closed chambers (Gallardo-Lara and Nogales 1987).

Composting involves three stages (Senesi 1989). In the first stage, readily degradable materials are decomposed. In the second, or thermophilic phase, cellulose and other similar material is degraded by activity of thermophilic microorganisms. In this phase there is the release of phytotoxins and destruction of animal and plant pathogens. In the third stage (maturation and stabilization phase), temperature declines, decomposition rates decrease and mesophilic organisms recolonize to create organic matter with a humic nature.

Types of compost include fresh, mature, cured, and vermicompost (Senesi 1989). Fresh compost often refers to an intermediate product of the thermophilic stage. This product has undergone partial decomposition, but is not yet stabilized. Mature compost is the final product of the stabilization stage and can be used as an organic fertilizer. Cured compost is a product of prolonged stabilization and mineralization beyond the stage of maturity to produce a highly humified product. Vermicompost is a product that occurs as earthworms feed on organic waste materials. Vermicompost is finely granulated and friable.

3.6.2 Sources

For optimum composting of organic materials several conditions are required. The materials must have a moisture content of 50% to 70%. Excessive moisture is not desirable because anaerobic condition will form. They must be piled or windrowed in such a way that internal temperatures in the heaps reach 50 to 72°C. Fertilization, particularly with N, and inoculation with soil to ensure that organisms are present will optimize decomposition. Frequent turning of the piles is necessary to provide oxygen to organisms. An alternative to turning is to make holes in the compost pile to insure that aeration is adequate. At the end of the composting process, particle size of residues should be small.

A number of cities in North America, particularly in the U.S.A. currently have pilot programmes to collect and compost municipal solid wastes (MSW) and yard wastes (Hegberg et al. 1990). The city of Edmonton had a pilot project in 1992 to collect and compost yard wastes from residents, but the programme was discontinued after one year due to funding cut backs (K. Lewis, City of Edmonton, Waste Management, telephone conversation January 5, 1993). No information has been available on laboratory analyses, cost of the product, or costs and effectiveness of the programme. Alberta Public Works also has a pilot project underway to compost yard wastes from government grounds in Edmonton. Results of the first year indicated that composting was a cost-effective way of dealing with yard wastes, and was cheaper than hauling and land-filling (Janzen et al. 1993). In 1993, potential uses for the compost and standards for the product will be examined. If this project is successful, the intention is to set up a composting program for government sites over the entire province (B. Ruzicky, Alberta Public Works Department, telephone conversation January 5, 1993).

At least one private company in the Edmonton area produces and sells composted yard waste. A mixture of garden wastes is obtained from private landscaping companies. The material is shredded and ground, windrowed, turned every 2 weeks with a front-end loader, put through a screen after 3 to 6 months and bagged in 2 kg bags. About 22 680 to 37 800 m^3 (30 000 to 50 000 yd^3) are produced annually at present, and there are no plans for expansion. Most is sold through horticultural distributors (Rumile Trucking Ltd., Edmonton, Alberta, telephone conversation October 23, 1992). No commercial scale operations involving the spreading of undecomposed yard wastes or MSW are currently underway in Alberta.

3.6.3 Chemistry

3.6.3.1 Chemistry of compost. Chemical properties of compost vary with type of material being composted and with the compost process. Concerns include possible high heavy metal content, major and minor plant nutrient content, and presence of potentially toxic organics. During decomposition, the C:N ratio of the material drops as CO_2 is given off. Decomposition is speeded up by fertilization. In some cities, sewage sludge is mixed with organic municipal waste because sewage sludge contains high levels of N (Epstein and Engel 1991). Chemical characteristics typical of good compost quality as specified by the Ontario Ministry of the Environment, are compared with characteristics of composted yard wastes from the Edmonton Area in Table 59. Note that the

Alberta material appears to be slightly lower in organic matter %, C:N ratio, total P and total K than recommended by Ontario Ministry of Environment (1991), but pH, EC, and total N fall within ranges given for good compost.

Chemical characteristics of yard waste, MSW, and sludge composts in New York and Minnesota are shown in Table 60. Both the yard waste and MSW compare favourably with the ranges given by Ontario Ministry of Environment (1991) for N, P, K, Ca, and Mg. Only N and P contents of the sludge compost compared favourably, however; K, Ca, and Mg were lower than recommended. Levels of heavy metals were very low in yard waste compost, which Epstein and Engel (1991) consider typical. Levels of most heavy metals were higher in MSW and sludge composts.

3.6.3.2 Nature of effect on soil chemistry. Gallardo-Lara and Nogales (1987) in a review of studies on the use of MSW compost as a potential soil amendment, reported that additions of MSW compost to soil resulted in changed chemical properties, including:

1. Increased pH towards neutrality when applied on acid soils, because of the compost's neutral or slightly alkaline pH;
2. Increased soluble salt and EC content, especially if large amounts of compost were applied;
3. Increased cation exchange capacity and buffering capacity;
4. Increased organic matter levels;
5. Increased calcium, potassium, and magnesium; and
6. Possible contamination of soils with heavy metals or other toxic elements with large quantities of compost.

Heavy metals of concern to human health are As, Cd, Cr, Cu, Pb, Hg, Mo, Ni, Sn and Zn. Metals occur at relatively low levels in yard waste composts, and are unlikely to build up to toxic levels. Application of large quantities of MSW composts, however, could contaminate soils with heavy metals (Epstein and Engel 1991).

Some elements, such as Cu, Ni, and Zn, are phytotoxic at levels well below those that affect humans (Epstein and Engel 1991). However, most metals in the compost are bound and relatively unavailable within the environment (Crawford and Johnson 1988, cited in Norland et al. 1991). Heavy metal uptake by plants is influenced by organic matter, pH, and cation

Table 59. Chemical and physical characteristics typical of good compost quality[a], and chemical characteristics of compost from Edmonton area.[b]

Parameter	Typical Range[a]	Alberta Compost Range[b]
Chemical Characteristics (dry weight basis)		
Organic matter %	>30%	19% to 34%
C:N ratio	22	13.8 to 17.5
EC (dS/cm)	<3.5 dS/cm	2.7 to 3.6
SAR	<5	not available
pH	5.5 to 8.5	7.0 to 7.3
Total N	0.6% (minimum)	0.7% to 1.1%
Total P	0.25% (minimum)	<0.01%
Total K	0.20% (minimum)	0.06% to 0.09%
Physical characteristics		
Particle size	<25mm	not available
Moisture content	30% to 55%	not available
Water holding capacity	3 times dry weight.	not available

[a] Source: Adapted from original table in Ontario Ministry of Environment (1991).

[b] Source: Rumile Trucking Ltd., Edmonton, Alberta, telephone conversation, October 23, 1992.

Table 60. Chemical characteristics of sample composts in New York and Minnesota[a] and maximum recommended compost concentrations in Ontario.[b]

Parameter	Samples composted in New York and Minnesota			
	Yard Waste	Municipal Solid Waste	Sludge	Maximum Recommended Compost Concentrations in Ontario[b] (mg/kg)
Nitrogen %	1.68	1.25	1.80	not applicable
Phosphorus %	0.17	0.48	1.28	not applicable
Potassium %	0.31	0.61	0.14	not applicable
Calcium %	3.04	4.23	1.75	not applicable
Magnesium %	0.53	0.62	0.24	not applicable
Arsenic ppmv[c]	0.0	3.0	5.0	10
Cadmium ppmv	0.6	4.0	10.0	3
Chromium ppmv	0.0	43.0	101.0	50
Copper ppmv	18.0	193.0	284.0	60
Lead ppmv	52.0	269.0	158.0	150
Mercury ppmv	0.3	1.5	3.5	0.15
Nickel ppmv	8.1	30.0	40.1	60
Zinc ppmv	101.0	572.0	728.0	500

[a] Adapted from original table in Epstein and Engel (1991).

[b] Adapted from original table in Gies (1992).

[c] ppmv = parts per million by volume.

exchange capacity. Gies (1992) lists maximum heavy metals and other contaminants recommended for compost products in Ontario (Table 60). Comparing these values with those found for samples of yard waste, MSW, and sludge, it is apparent that both the MSW and sludge composts exceeded recommended limits for a number of parameters including Cd, Cr (sludge only), Cu, Pb, Hg and Zn. Mercury content of all three compost products exceeded the recommended limit. Gies (1992) also lists maximum allowable concentrations of PCB's as 0.5 mg/kg, and of plastics and total other non-biodegradable particulate matter as 1.0% and 2.0% respectively.

Several pilot projects in the United States are currently underway to examine effects of adding undecomposed yard wastes directly to the soil. Results suggest that supplemental nitrogen is required for degradation of leaves because of the high C:N ratio in leaves (40 to 80). It is recommended that soil should be monitored for chemical and metal contaminants before and after applications. Proper management is needed so that nitrate levels are not elevated above acceptable standards and do not pose problems to groundwater sources (Hegberg et al. 1990).

3.6.4 Physical Properties

3.6.4.1 Physical properties of compost. Important physical properties of compost include moisture content, particle size, and level of inerts like sand, plastic, and glass (Epstein and Engel 1991). Physical characteristics typical of good compost quality are shown in Table 59.

3.6.4.2 Effect of compost on soil physical properties. The effects of composted town refuse on soil physical properties have been found to be similar to the effects of many other organic amendments (Gallardo-Lara and Nogales 1987). After compost incorporation:

1. Soil density decreased, most likely due to low density of compost and its tendency to increase soil pore size;
2. Total pore volume increased;
3. Water infiltration and air permeability increased;
4. Soil water holding capacity increased;
5. Formation and stabilization of soil aggregates increased; and
6. Soil structure improved.

3.6.5 Biology

3.6.5.1 Biology of compost. Occurrence of pathogens and the state of decomposition of the compost cause concern for the public (Epstein and Engel 1991). Studies have shown, however, that most weed seeds and plant and animal pathogens are destroyed in the thermophilic stage of composting (Ontario Ministry of Environment 1991; Senesi 1989). Compost processing temperatures of 55°C or higher were found to kill most weed seeds and destroy most pathogens. Where compost is not stable (decomposition is not complete) the material can inhibit plant growth and produce odours.

3.6.5.2 Effect of compost on soil biology. Additions of compost with C:N ratios greater than 30 can result in nitrogen deficiency to crops due to net N immobilization (Gallardo-Lara and Nogales 1987). Immobilization was not observed when compost C:N ratios were less than 20. Other effects on soil biology of composted yard wastes or MSW should be similar to the effects of other organic amendments like peat or straw.

3.6.6 Application

3.6.6.1 Methods. Composted yard waste and MSW are generally spread onto the soil and incorporated.

3.6.6.2 Timing. No studies dealing directly with the timing of applications of yard waste, MSW, compost, or undecomposed yard wastes were found. However, as with other organic amendments, materials are best incorporated into the soil immediately. If the material is only partially decomposed, then it should be applied to soil a few weeks prior to seeding. Application in winter is not recommended.

3.6.6.3 Rates. There are currently no official recommendations on rates of compost application for Alberta. In British Columbia (British Columbia Ministry of Environment, Lands and Parks 1992) and some American States, rates are limited by concentrations of heavy metals in the product. High application rates of undecomposed wastes should be avoided because immobilization of important plant nutrients would occur.

Rates of application of 8, 16, 32 and 64 Mg/ha of MSW compost was studied in a greenhouse using sandy soil in Florida (Hortenstine and Rothwell 1973). Plant height and weight significantly increased when compost was added at any rate compared to the control. Plant yields from the two highest compost rates were equal or better than the mineral fertilizer. Compost at any rate maintained the soil pH at control levels, whereas there was a drop in pH with the use of mineral fertilizer. Water content at 0.1 bar tension increased with each increment of compost compared to control or fertilizer treatment. At 15 bars, compost applied at rates of 8 Mg/ha had no effect on water retention and there was no significant effect among rates above 16 Mg/ha. The ability of compost to increase water holding capacity is considered to be one of the most beneficial characteristics of composted MSW. Compost also significantly increased the CEC and organic matter content of the soil when applied at rates of 64 Mg/ha. Small increases in EC were observed when compost was applied at the highest rate of 64 Mg/ha.

If yard wastes are spread without composting, Hegberg et al. (1990) recommended that rates should not exceed 44.8 Mg/ha (20 T/ac). At higher rates, adequate incorporation into the soil is difficult even with a rototiller, and the high amounts of nitrogen fertilizer which must be added to lower C:N ratios could result in groundwater contamination.

3.6.6.4 Frequency. Except where heavy metal concentrations are high, there need be no restrictions on the frequency of application of yard and MSW compost. It is more useful to split applications rather than apply a large amount once. If the compost is not stable, or if yard wastes are spread without composting, the high rates of nitrogen fertilizer required to reduce C:N ratios to between 20 and 30 could limit frequency of application. Several smaller applications of compost is preferable to the application of a single large one.

3.6.6.5 Equipment. Compost can be directly spread on the land using standard fertilizer spreaders or manure spreaders, depending on the physical properties of the material. Uncomposted yard wastes can be applied directly to the soil using a manure spreader with beaters. Rototilling of uncomposted materials into the soil appears to be more satisfactory than discing (Peterson et al. 1989, cited in Hegberg et al. 1990).

3.6.7 Costs

Composted MSW is not available in Alberta. Composted yard waste produced by the City of Edmonton and other municipalities was not sold commercially, and is no longer available. A commercial company supplying composted yard wastes to landscaping companies charged \$29.00/m^3 (\$22.00/yd^3) in 1992.

Hegberg et al. (1990) concluded that direct spreading of yard wastes was slightly cheaper than composting. However, ease of handling, transporting, and spreading of the composted product, as well as benefits from not having to add large amounts of nitrogen fertilizer could outweigh the slightly higher costs of composting.

3.6.8 Longevity of Effects

No information is available on the long term effects of the addition of municipal and yard compost to soil.

3.6.9 Summary

3.6.9.1 Benefits. Additions of composted yard waste and MSW to soils can result in (Epstein and Engel 1991; Gallardo-Lara and Nogales 1987):

1. Increased organic matter content of soil;
2. Improved soil structure, increased porosity, and decreased bulk density;
3. Increased water holding capacity;
4. Increased infiltration and permeability of heavy soils;
5. Reduced water losses and leaching in sandy soils;
6. Increased cation exchange capacity and buffering capacity of soils; and
7. Control or suppression of some plant pathogens.

Benefits of direct land spreading yard waste to farmland without composting include (Smith 1990 and On-Land Environmental Opportunities 1990; both cited in Hegberg et al. 1990):

1. Organic matter added to soil at minimal cost;
2. Reduced wind and water erosion on sites with land spreading;
3. Expense of land application is less than that of composting; and
4. Composted product does not have to be marketed.

Benefits of compost additions are not permanent. Compost amendments do not provide a permanent increase in soil organic matter. The establishment of plants on the soil is important for the long term maintenance of adequate soil organic matter levels. Growing plants will add a continual supply of carbon to the soil.

3.6.9.2 Drawbacks. Drawbacks to adding composted yard waste and MSW to soils can include (Gallardo-Lara and Nogales 1987):

1. Possibilities of increased organic and heavy metal contamination;
2. Slightly increased electrical conductivity of soils;
3. Seed germination possibly inhibited with large additions of compost; and
4. High C:N ratios which can immobilize soil nitrogen.

Problems associated with direct land spreading of uncomposted yard wastes include (Nally 1989 and Peterson et al. 1989; both cited in Hegberg et al. 1990):

1. Yard waste may contain brush, glass, metal, plastic and other debris;
2. Raw grass and leaves are bulky and difficult to handle;
3. Spreading large volumes of material is time consuming, increases fuel costs and soil compaction;
4. Grass clippings become odorous if stockpiled prior to spreading or if poorly incorporated; and
5. Large amounts of nitrogen fertilizer must be added to reduce high C:N ratios.

3.6.10 Use for Reclamation

No record of composted yard waste, MSW, or uncomposted yard waste being used for reclamation purposes in Alberta was found. However, a study on composted MSW used to revegetate taconite tailings in Minnesota indicated that 90- or 180-day MSW composts can be used as organic amendments when applied at rates of 40 Mg/ha as a minimum, and when the tailings are fertilized with 448 kg/ha of 18-46-0 fertilizer (Norland, et al 1991). No changes were observed in the chemical properties of the taconite tailings as a result of the MSW compost additions at the rates applied.

3.6.11 Recommendations for Use in Alberta

At the time of writing, no guidelines for the use of yard waste and MSW compost in Alberta were available. However, Alberta Environment Protection plans to release final guidelines regarding quality criteria for compost in the spring of 1994 (Vern Albush, Recycling Programs Advisor, Alberta Environment Wastes and Chemicals Division, Recycling Branch, telephone conversation June 28, 1993). Interim guidelines for the production and use of aerobic compost in Ontario (Ontario Ministry of the Environment 1991), and draft guidelines for British Columbia (British Columbia Ministry of Environment, Lands and Parks 1992) have been developed. In Ontario, compost is classified according to the following criteria:

1. Type of waste material processed (yard waste, source separated compostable waste, and municipal solid waste);
2. Product maturity (mature, semi-mature, and fresh);
3. Foreign matter content by dry weight ($\leq 1\%$, $>1\%$ to $\leq 2\%$, and $>2\%$ to $\leq 10\%$);
4. Heavy metal concentrations (concentration codes used for compost classification, Table 61);
5. pH (between 5.0 and 8.0); and
5. Electrical conductivity (≤ 2, >2 to 3, and >3 dS/m).

Compost types and their use restrictions are shown in Table 62. In unrestricted distribution (Types SS and A), compost products may be applied to agricultural land, home gardens, horticultural and nursery industries, and any other business that requires a high quality product (Ontario Ministry of the Environment 1991). Maximum acceptable cumulative additions of heavy metals that can be applied to a site are shown in Table 63. The system to be used in British Columbia is similar. Until formal guidelines are developed for Alberta, it is recommended that the Ontario guidelines be followed.

Table 61. Heavy metal concentration codes for compost (mg/kg dry weight).[a]

	Concentration Codes for Compost Classification			
Heavy Metal	1	2	3	4
Arsenic	<15	13-30	30-50	>50
Cadmium	<2.6	2.6-5.0	5-20	>20
Chromium	<210	210-250	250-800	>800
Cobalt	<26	26-50	50-300	>300
Copper	<100	<100	100-500	>500
Lead	<150	150-500	500-1000	>1000
Mercury	<0.8	0.8-2	2-10	>10
Molybdenum	<5	5-10	10-40	>40
Nickel	<50	50-100	100-500	>500
Selenium	<2	2-3	3-10	>10
Zinc	<315	315-500	500-1500	>1500

[a] Source: Ontario Ministry of the Environment (1991).

3.7 HUMATES

Humus is the relatively stable component of soil organic matter. It is composed of organic matter and contains fulvic acid, humic acid, humin, and nonhumic material (Stevenson 1982a). Humic acids found in humic material, include humic acid, ulmic acid and fulvic acid. Natural plant derived humus serves as a reservoir for nitrogen, phosphorus, and sulphur for plants and as a source of energy for microorganisms. It improves soil structure, drainage, and aeration, and increases soil water holding, buffering, and exchange capacity (Stevenson 1986). Stevenson (1986) defines commercial humates as oxidized lignites (leonardite) or products derived from them, typically overlying lignite coal deposits. Humates consist of 30% to 60% humic acids. They are undesirable as fuel sources because of their low fuel value they are usually discarded during mining operations (Stevenson 1986). Large deposits of oxidized lignites have been mined in North Dakota, Texas, New Mexico, and Idaho. Because of their high humic acid content, they have been considered for use as soil additives.

Table 62. Compost types and restrictions.[a]

Type	Waste Material Present	Product Maturity	Foreign Matter Present	Heavy Metal Concentration Code	Use Restriction
SS	Source separated compostable waste	Mature or semi-mature	<1% and no sharp objects	1	Unrestricted distribution
A	Municipal solid waste	Mature	≤1% and no sharp objects	1	Unrestricted distribution
B	Municipal solid waste	Mature or semi-mature	≤2% and no sharp objects	1 or 2	Parks, forested land and non-food applications in horticultural and nursery industry
C	Municipal solid waste	Mature or semi-mature	≤10% and no sharp objects	1, 2, or 3	Forested land and non-food applications in horticultural and nursery industry
D	Yard waste/ municipal solid waste	Fresh	≤10%	1, 2, or 3	Only on land reclamation projects with limited potential for public contact
E	Municipal solid waste	All	Any	4	Dispose of in a landfill

[a] Source: Adapted from original table in Ontario Ministry of the Environment (1991).

Table 63. Maximum acceptable cumulative additions of heavy metal to soil.[a]

Heavy Metal	Maximum Cumulative Rate (kg/ha)
Arsenic	15
Cadmium	4
Cobalt	30
Lead	100
Mercury	1
Molybdenum	4
Nickel	36
Selenium	2.8
Zinc	370

[a] Source: Ontario Ministry of the Environment (1991).

Commercial humates have been introduced to the marketplace with claims that they improve soil conditions and plant growth. Some of the benefits that have been claimed for humates include (Humate Canada Limited, Calgary, Alberta, telephone conversation, October 22, 1992; Linderman 1989; Obreza et al. 1989; McAllister 1983; Welborn 1982):

1. Increases in buffering and exchange capacities of soil;
2. Chelation of mineral elements;
3. Enhancement of microbial activity;
4. Alteration of root membrane permeability;
5. Increases in nutrient uptake;
6. Increases in efficiency of fertilizer utilization;
7. Increases in root size and mass;
8. Alleviation of compaction;
9. Reduction of stress and disease of plants;
10. Retention of water in soil;
11. Improvement of tilth;
12. Increases in soil organic matter,
13. Increases in crop yields and earlier maturation of crops; and
14. Stimulation of germination.

Whether commercial humates can fulfill these expectations is still not fully determined. Studies on the additions of commercial humates to soils have been inconclusive (Stevenson 1986).

3.7.1 Types

There are two main types of commercial humates used for agricultural purposes (Stevenson 1986): mined lignites and ammonium humate fertilizer. Mined lignites have been crushed and pulverized, and do not contain significant amounts of N, P, or K. They have low water solubility. Ammonium humate fertilizer is soluble and contains available N, P, and K. Some manufacturers extract the humic acids and sell them in concentrated liquid form, while others add major and minor nutrients to fortify the product. Still others sell natural humate products from sources other than leonardite (McAllister 1983).

Coal humates have different chemical and physical properties from humus in soil (McAllister 1983; Stevenson 1986). Coal humates do not have proteins or polysaccharides and contain little fulvic acid. They also have higher carbon content than soil humic acids.

3.7.2 Sources

Commercial humates are available from a number of distributors in Alberta. Most are derived from deposits in the United States.

3.7.3 Chemistry

Highlights of studies dealing with the chemical, physical, and biological effects of humates on soil, and their effects on plant growth, are presented in Table 64.

3.7.3.1 Chemistry of humates. Typical chemical composition of leonardite from North Dakota is presented in Table 65. This table indicates that leonardite does not supply substantial mineral nutrients. However, it is high in organic matter and humate content. The analyses of a weathered sub-bituminous coal from Sheerness, Alberta and an ammoniated sulfomethylated humic acid product also indicate that carbon contents are high, but mineral nutrients are low (Table 66).

3.7.3.2 Effect of humates on soil chemistry. Studies examining the effects of the addition of humate, leonardite, or lignite to soil, are summarized in Table 64.

3.7.3.2.1 Soil organic matter. Several reviews have indicated that additions of commercial humates at the recommended or feasible rates may not result in significant increases in organic matter (McAllister 1983; Stevenson 1986). For example, soil with an organic matter content of 3% contains 67 400 kg of organic matter per hectare to plough depth (Stevenson 1986). Additions of 500 kg/ha commercial humate with 60% humic matter would increase the organic matter by only 0.01%. Often, the use of commercial humates is recommended along with crop rotation, addition of crop residues or manures to soil, and tillage and cultural practices to conserve moisture, all of which tend to build up soil organic matter. It is often difficult to separate increases in soil organic matter due to cultural practices from increases due to humate addition.

Increases in soil organic matter that occur with large additions of humates may be short lived. Lignite, modified lignite (lignite with a lowered C:N ratio), and lignite mixed with farm manure were applied to sandy soils at rates of 3.2 to 7.6 Mg/ha (3.57 to 8.33 tons/ha) in Egypt (Zein El-Abedine and Hosny 1982). Maximum levels of soil organic matter were reached in 6 weeks, after which organic matter decreased to near control levels.

Table 64. Summary of research on humates.

Reference	Location	Soil Type	Humate Type	Rate	Duration	Effect
Moschopedis (1974)	Alberta (field and laboratory)	Sandy	Ammoniated sulfomethylated humate	56, 112, and 224 kg/ha available N (growth experiment). 0.27%, 0.54%, and 2.70% by weight (aggregation experiment). 0% to 10% by weight (moisture retention exp.). 300 and 600 ppm available N (hydraulic conductivity exp.). 100 and 200 ppm available N (leaching experiment).	1 year	Increase in aggregate mean weight diameter. Decrease in hydraulic conductivity of sandy soils. Decrease in leaching rates. Increase in soil moisture content. No effect on plant growth without ammonium fertilizer.
Moschopedis and Mitchell (1974)	Alberta (laboratory)	Athabasca oil sand formation sand	Sulfomethylated humic acids	0.27%, 0.54%, and 2.7% by wt (aggregation experiment). 100, 200, 300, and 600 ppm available N (hydraulic conductivity experiment).	unknown	Increase in aggregate mean weight diameter. Decrease in hydraulic conductivity.
Brownell et al. (1987)	California	Unknown	Leonardite extract	10 litres/ha + fertilizer, applied as an early season soil treatment, and as post emergent foliar spray	1 to 4 years	Increase in grape, cotton, and tomato yields.
Wallace and Wallace (1986)	California (greenhouse study)	4 soils low in organic matter	Lignite and polyacrylamide	9 Mg/ha lignite, 450 kg/ha polyacrylamide, applied separately and together. Nitrogen applied to all treatments.	Unknown	Polyacrylamide and lignite together gave best results for germination and plant growth.
Abouguendia et al. (1986)	Saskatchewan	3 soils	Leonardite	0.75 to 3.00 kg/m^2	2 years	No significant difference in any soil parameter. No significant difference in plant growth.
Dzhanpeisov et al. (1984)	USSR (laboratory)	Sandy loam, loamy sand and mountain forest soil	Humic acid copolymerized with vinyl monomers at 10:1 ratio	0% to 10% of soil weight, incorporated to 10 cm in sandy soil and 10 to 20 cm in mountain forest soil.	Unknown	Increased in amount of water stable aggregates from 2% to 33% to 99%. Rate of 2% to 3% soil weight was effective. Conditioning effect lasted 3 months. Effects most pronounced on coarse textured material.

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Table 64. Concluded.

Reference	Location	Soil Type	Humate Type	Rate	Duration	Effect
Zein El-Abedine and Hosny (1982)	Egypt (field and laboratory study)	Sand	Lignite Modified lignite with C:N ratio lowered to 30 with fertilizers lignite + farm manure mixed 80% - 20%	3.57, 5.95, and 8.33 Mg/ha	Unknown	After 6 weeks, microbial counts similar to those of control. Increased soil organic matter for all levels of treatment, maximum reached in 6 weeks, then decreased. Increased CEC to 20 cm, increase related to amounts of lignite added. After 12 weeks, drop in moisture retention for basic and modified lignite treatments, but no drop in lignite + manure mix. Increased yields with increasing levels of lignite.
Kollman (1979)	North Dakota	Coal mine spoil	Leonardite	0 and 100 Mg/ha, + fertilizer	2 years	Leonardite was beneficial to legumes, detrimental to grasses. Decreased upward movement of salts from sodic spoils to topsoils.

Table 65. Typical analysis of leonardite from North Dakota.[a]

Parameter	Percent
Humates	71
Total organic matter	73
Nitrogen	0.08
Phosphorus	0.00
Potassium	0.16
Calcium	9.00
Magnesium	2.30
Sodium	0.37
Zinc	0.00
Manganese	0.41
Copper	0.04
Sulphur	0.00
Moisture	2.3

[a] Source: Adapted from original table in McAllister (1983).

Table 66. Analysis of humic acid and sulfomethylated humic acid product.[a]

Analysis Results (%)	Humic acid[b]	Sulfomethylated humic acid product
Moisture	25.2	5.3
Ash	12.9	17.9
Carbon	39.1	na
Hydrogen	2.2	na
Sulphur	0.4	2.0
Nitrogen	1.3	5.3
NH_3	na[c]	3.7

[a] Source: Adapted from original table in Moschopedis (1974).

[b] Weathered sub-bituminous coal from Sheerness, Alberta, locally known as "rusty coal".

[c] Not analysed.

3.7.3.2.2 Nutrient status. There have been conflicting reports about the effect of humates on phosphorus in soil. Leonardite additions have decreased the phosphorous diffusion coefficient (Harrel and Saeed 1977, cited in Abouguendia et al. 1986), increased phosphorous availability (Safaya and Wali 1979, cited in Abouguendia et al. 1986) and had no effect on phosphorous mobility (Duplessis and MacKenzie 1983, cited in Abouguendia et al. 1986).

In a field study in Saskatchewan on three different agricultural soils, leonardite was applied at rates of 0.75 to 3.0 kg/m^2, and resulted in no significant differences in pH, EC, water soluble cations, extractable cations, or available N, P, and K (Abouguendia et al. 1986). The concluded that under these field conditions, leonardite had no soil conditioning effects, in contrast to beneficial effects reported in other literature. Differences may be related to differences in soil characteristics, amendment properties and rates, and experimental conditions. In another study on sodic coal spoil, pH was lowered by 0.2 to 0.3 units with applications of leonardite (Safaya and Wali 1979, cited in Abouguendia et al. 1986).

3.7.3.2.3 Soil salinity. Leonardite additions to saline and alkaline soils resulted in lowered EC, SAR, water soluble Na, Cl, and Ca (O'Donnell 1973a). Reductions in total soluble salts to a depth of 90 cm were recorded after leonardite was added to saline and alkaline soils (Dhawan and Mahajan 1964, cited in Abouguendia et al. 1986). Field studies using leonardite for coal mine spoil reclamation in North Dakota have shown that the upward movement of salts from sodic spoils to topsoil is decreased with leonardite additions (Kollman 1979). This effect was attributed to the restriction of water movement in the spoil material by leonardite.

3.7.4 Physical Properties

3.7.4.1 Physical properties of humates. No information was available on the physical properties of humates.

3.7.4.2 Effect of humates on soil physical properties. Ammoniated sulfomethylated humates produced from low-grade, oxidized sub-bituminous coal from the upper seam at Sheerness, Alberta, were tested in the laboratory and on a sandy soil from Youngstown, Alberta, and compared to fertilizer treatments (Moschopedis 1974). The ammoniated sulfomethylated humates, applied at rates of 0.54% and 2.70% by weight, significantly increased the diameter of aggregates from 0.21 mm to

0.57 and 1.56 mm, respectively. Hydraulic conductivity decreased, leaching rate decreased, and moisture content increased. Both ammonium nitrate and ammonium sulphate fertilizers were totally leached out of laboratory soils after 10 minutes, but 66% and 35% of the ammoniated sulfomethylated humates remained after 10 and 30 minutes leaching, respectively, suggesting some binding mechanism.

A similar study examined the performance of ammoniated sulfomethylated humates as soil conditioners for sandy tailings of the Athabasca oil sands mining area in Alberta. At rates of 0.54% and 2.70% by weight ammoniated sulfomethylated humates, mean weight diameters of aggregates increased from 0.29 mm to 0.34 and 0.40 mm, respectively. This effect was attributed to the cementation of particles by humic additives (Moschopedis and Mitchell 1974). Hydraulic conductivity of the sandy tailings decreased with applications of ammoniated sulfomethylated humates.

Dzhanpeisov et al. (1984), in a laboratory study to determine the effect of humic acids from coal copolymerized with vinyl monomers, reported that synthetic polymers were effective for improving structure of the soil and that the effects were long-lasting. The polymers were expensive, however.

3.7.5 Biology

3.7.5.1 Biology of humates. No information on the biology of humates was found.

3.7.5.2 Effect of humates on soil biology. In a laboratory experiment, Zein El-Abedine and Hosny (1982) found that when coarse lignite, fine lignite, and modified lignite were mixed with the soil, there were slight increases in numbers of fungi, actinomycetes, and total bacteria. However, these effects disappeared after 6 weeks.

3.7.5.3 Effect of humates on plant growth. Humates appear to have no consistent effects on the growth of plants. In a field study near Youngstown, Alberta, ammoniated sulfomethylated humates added to sandy soils were compared with additions of ammonium nitrate and ammonium sulphate to determine their effects on growth of a bromegrass and rye mix (Moschopedis 1974). At the same levels of nitrogen per hectare, total yields for plots treated with ammonium sulphate and ammoniated sulfomethylated humates were significantly greater than for plots treated with ammonium nitrate. The author concluded that ammoniated sulfomethylated humates had comparable effects to other nitrogen-carrying fertilizers.

In contrast to the Alberta study, Abouguendia et al. (1986) in Saskatchewan found no stimulation of growth when leonardite was applied to at rates of 0.75 to 3.00 kg/m^2. In this study, leonardite was not treated to increase N content. Stevenson (1986) suggests that humic acids must be in water soluble form to be taken up by plants. Mined humates are insoluble and therefore would not stimulate plant growth.

Other studies have also found diverse effects of leonardite additions. A laboratory rooting study by O'Donnell (1973b), noted a stimulation of plant growth and field research in California indicated increased growth of grapes, tomatoes, and wheat (Brownell et al. 1987; Wallace and Wallace 1986). On the other hand, for coal mine spoil in North Dakota, leonardite additions resulted in grass and legume yields similar to controls during the first year (Kollman 1979); in the second year, grass and weeds were more prevalent on non-leonardite treated soils, whereas legumes were more prevalent on the leonardite treated soils. Similar trends were also noted in a greenhouse experiment (Safaya and Wali 1979, cited in Kollman 1979). In another study, leonardite reduced Na content in yellow sweetclover and caused an increase in growth, but the opposite occurred for northern wheatgrass (Safaya and Wali (1979, cited in Abouguendia et al. 1986).

3.7.6 Recommendations for Use in Alberta

In view of the highly variable results obtained from research on humates and related materials, and relatively high costs for the material, the use of humates as a soil amendment for reclamation in Alberta is not recommended. Better sources of organic matter should be available in almost all situations.

3.8 OTHER ORGANIC MATERIALS

3.8.1 Vermicomposts

Vermicompost is the waste material produced by earthworms when they feed on organic materials (Hervas et al. 1989). Using earthworms reduces the length of time required to decompose organic materials compared to other methods of composting, and may also increase the number of microorganisms in the material being composted (Edwards et al. 1984). Chemical analyses by Hervas et al. (1989), of vermicomposts derived from various sources are presented in Table 67. Organic C and total organic matter of the vermicomposts are high, similar to other types

Table 67. Chemical composition of vermicomposts from various sources.[a]

Chemical Property	Mixed Animal Manures	Municipal Solid Waste	Cow Manure	Sewage Sludge	Animal Manure	Unknown
Moisture %	38	36	47	53	58	40
Ash %	67	76	43	45	60	63
Total organic matter %	33	24	57	55	40	37
Organic C %	14	16	22	22	17	18
pH	6.8	6.9	6.7	6.8	7.0	6.7
Fraction <2mm (%)	99.2	83.3	95.3	98.3	95.7	97.5
Humic Acid %	6.0	3.6	17.2	13.0	5.0	5.4
Macronutrients (%)						
Nitrogen	1.3	1.1	2.4	2.3	1.4	1.0
Phosphorus	0.7	0.4	1.0	0.9	0.8	0.8
Potassium	1.1	0.9	1.2	1.4	1.5	2.3
Calcium	14.6	11.5	9.2	10.4	11.8	7.1
Magnesium	1.0	0.6	0.9	1.0	0.8	1.6
Sodium	0.6	1.0	0.3	0.4	0.3	0.9
Sulphur	0.4	0.3	0.6	0.6	0.5	1.4
Micronutrients (mg/kg)						
Iron	6945	12850	6070	5210	8595	18800
Manganese	340	665	430	405	365	630
Copper	265	430	235	490	270	400
Zinc	160	75	65	115	67	150
Boron	11	11	26	21	18	18
Heavy Metals (mg/kg)						
Cadmium	3	3	2	2	2	4
Nickel	27	25	17	36	20	43
Chromium	33	50	14	290	19	73
Lead	71	193	31	99	24	74
Cobalt	13	10	8	9	9	18

[a] Source: Hervas et al. (1989).

of composts, making them a good source of organic matter for soils. In addition, vermicomposts generally have good structure, porosity, and moisture-holding capacity (Edwards et al. 1984).

Methods of large-scale vermicomposting of animal manure and sewage sludge have been tested with some success elsewhere (Edwards et al. 1984), but no similar work has been carried out in Alberta. At present there do not appear to be any major commercial sources of vermicompost in Alberta.

3.8.2 Spent Mushroom Compost

Spent mushroom compost is the used and discarded growing medium from commercial mushroom production. It is commonly reused as a soil amendment. In Alberta mushroom producers sell spent mushroom compost, mainly for horticultural or landscaping use. A typical mix is 75% wheat or rye straw, and 25% horse manure, supplemented with chicken manure to increase the N content. The material is composted in piles, then steam sterilized to prevent weed growth. Some producers may also include peat moss. Total amount produced in Alberta is not known (Prairie Mushrooms Ltd., Sherwood Park, and Superior Mushroom Farms Ltd., Ardrossan, telephone calls, December 21, 1992).

Vogel and Rothwell (1988) evaluated the effects of mushroom compost as an amendment on acid coal-mine spoil in a greenhouse study. Mushroom compost (Table 68) was incorporated into spoil at rates of 56, 112 and 168 tonnes/ha. Plant yields on spoil amended with mushroom compost were several fold greater than on spoil amended with lime and fertilizer only. The higher plant yields were attributed to high levels of N, P, and K, and organic matter in the compost material.

3.8.3 Others. Other organic materials that have been used as soil amendments include aquatic weeds (Tate and Riemer 1988), algae (Johnson 1984), tomato waste (Timm et al. 1980), and sterilized, dried mycelial residue from commercial antibiotic production (Glatzel et al. 1989). However, none of these products are available in quantity in Alberta.

Table 68. Chemical properties of mushroom compost used to amend acid mine spoils.[a]

Property[b]	Mushroom Compost
pH	6.8
N (%)	2.64
P (ppm)	7148
K (ppm)	19 352
Ca (ppm)	66 857
Mg (ppm)	14 823
Fe (ppm)	6183
Al (ppm)	5273

[a] Source: Vogel and Rothwell (1988).

[b] Analyses on ovendry material.

4. SUMMARY AND CONCLUSIONS

Soil organic amendments should not take the place of normal topsoil salvage, storage and replacement. However, when some topsoil degradation has occurred, or on old disturbances where no topsoil was salvaged, an organic amendment may be required. The type of organic amendment chosen for a particular reclamation site will depend on:

1. Purpose of the amendment (control erosion, increase soil organic matter, add nutrients, improve soil physical properties);
2. Cost, transportation distance and availability of amendment (some amendments may be easily available in certain areas, while others are not); and
3. Location of the reclamation site, its future landuse, climate, soil, and landscape features;

There are a large variety of sources of organic amendments in Alberta. Not all are well suited to every reclamation situation; however, there are sources of organic materials suitable for use as amendments everywhere in the province. It is important to know the likely effects of an amendment, and potential problems which could arise with its use. Because of the wide variety of amendments with some potential for use in reclamation, types of organic matter amendments discussed in this literature review are summarized in Table 69. Information on the usefulness of each amendment for controlling erosion, increasing soil organic matter, improving soil nutrient status, and improving soil physical properties are outlined. Possible problems associated with each amendment are also indicated. Readers should refer to the sections of each type of amendment for more details.

Table 69. Summary of organic amendments for reclamation use.

Amendment	Erosion Control	Increase Soil Organic Matter	Improve Soil Nutrient Status	Improve Soil Physical Properties	Possible Problems	Availability in Alberta	Application	Comments
Animal Manure	Some long term control	Good source of organic matter; immediate and long term effects	Good source of N, P, K, and S; increases CEC	Improves soil aggregation; increases water holding capacity, infiltration, and permeability; decreases bulk density, immediate and long term effects	Possible increase in soil salinity and sodicity or decrease in pH with long term heavy applications; weed introduction unless composted; can pollute surface and groundwater with nitrate if excessive rates are applied; some possibility of heavy metal contamination with long term heavy applications	Feedlot manure readily available in southern Alberta; cattle manure found throughout agricultural areas; other types may be available close to specific reclamation sites; composted manure only available commercially in S. Alberta at present, but composting could become more widespread if demand increases	Work into soil immediately after application; don't apply fresh manure immediately before seeding; don't exceed recommended rates for Alberta	Composted manure is a good choice if available, if not use well rotted manure; manure has an additional benefit of stimulating soil biological activity
Green Manure	Good erosion control once established if crop is not incorporated	Long term increase only	Good source of N if grass-legume mix is used	Improves soil aggregation; increases water holding capacity, infiltration, and permeability; decreases bulk density; long term benefits only	Can use up soil moisture required for following crop in dry areas; soil improvements are slow; there may be no marketable crop during plow down year; if legume is not included in the seeding mix, soil N may be immobilized, making fertilizer N additions necessary	Green manure crop can be grown almost anywhere in Alberta; may be less successful in the Brown Soil Zone	If legumes are included in the seeding mix, they must be inoculated with appropriate rhizobium; if mature plant material is turned under, or if no legume in mix, supplemental N will be required	
Forages	Good erosion control once established	Long term increase only	Good source of N if grass-legume mix is used	Improves snow trapping, water holding capacity and infiltration; decreases bulk density; relieves compaction; long term benefits only	Few problems with forages provided seeding mix, rates, and methods are appropriate for the area	Forages can be grown anywhere in Alberta, provided suitable grass and legume species are selected	Legumes included in the seed mix must be inoculated with appropriate rhizobium	Grass-legume forage mixtures are appropriate for most reclamation applications

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Table 69. Continued.

Amendment	Erosion Control	Increase Soil Organic Matter	Improve Soil Nutrient Status	Improve Soil Physical Properties	Possible Problems	Availability in Alberta	Application	Comments
Straw	Best erosion control if left standing or surface applied as a mulch.	Long term increase, but slow decomposition. Straw is more resistant to decomposition than most amendments; incorporate straw to increase soil organic matter	Soil N will be immobilized if N fertilizer is not supplied	Improves water infiltration; improves snow trapping if standing, moderates soil temperatures in standing or mulched; decreases bulk density if incorporated or possibly crimped; immediate and long term benefits	Supplemental N fertilizer will be required to prevent immobilization of soil N	Straw is commonly available throughout the agricultural areas of Alberta; may be harder to find in areas where conservation tillage is being extensively practised	May be left as standing stubble, applied as a surface mulch, crimped into the soil surface, or incorporated, as required; supplemental N fertilizer required	Cereal straws are more effective than oil seed straws; rate of decomposition is dependent on amount of N available in soil
Peat	Not normally used for erosion control	Increases soil organic matter, but is slow to decompose	Small increase in plant nutrients; may cause decrease in pH requiring liming	Generally an increase in infiltration, permeability, water holding capacity in most cases; usually a decrease in bulk density;	Not a very good source of plant nutrients, high rates of fertilizer will be required; liming may be needed to raise pH; high rates of peat often needed for benefits to be obvious; micronutrient deficiency may be a problem with very heavy additions; peat must be handled carefully to prevent drying out	Available in small quantities from horticulture outlets throughout the province; available in quantity from some peat producers mainly in central and northern Alberta; in some northern areas may be salvaged from disturbance site	Incorporate into soil; supplemental fertilization, especially N, will be required	Little information on the longevity of peat in soil
Wood Waste	Can be useful for erosion control; chips as a mulch or papermill sludge incorporated	Increases soil organic matter but large amounts of soil N required for decomposition	Poor source of plant nutrients	Improved water retention, aeration, infiltration; as a mulch regulates soil temperature, conserves soil moisture, hinders weed emergence	Not a good source of plant nutrients; high rates of N must be added to prevent N immobilization and promote decomposition; SAR may increase if used to amend sodic materials; may increase concentration of some heavy metals with repeated long term applications	Available in areas with forest industries, mainly central and northern Alberta	Supplemental N fertilizer will be required whether applied as a mulch or incorporated	Longevity of effect will depend on amount of soil N available, type of wood waste used, type of application

continued...

Table 69. Concluded.

Amendment	Erosion Control	Increase Soil Organic Matter	Improve Soil Nutrient Status	Improve Soil Physical Properties	Possible Problems	Availability in Alberta	Application	Comments
Sewage sludge	Not normally used for erosion control	Limited or no increase in soil organic matter	Good source of N, P, K; increase in CEC; may decrease soil pH with long term additions	Decrease in soil bulk density and strength; increase in soil water retention;	May increase soil salinity and decrease soil pH with long term applications; may cause surface and groundwater pollution with heavy application, or if not worked in; may increase concentration of heavy metals in soil with repeated heavy application; risk of pathogens	May be available from cities in Alberta; could be made available from numerous towns and villages throughout the province if demand develops	Can be injected or spread and incorporated, depending on available equipment	Little information available on longevity of effects; likely similar to animal manures
Municipal and Yard Compost	Could be used for erosion control as a mulch	Increase in soil organic matter	Source of Ca, Mg, and K; increased CEC; possible increase in EC over time	Increased soil water retention, infiltration, air porosity; decrease bulk density; improved aggregation and soil structure	Risk of contamination with heavy metals or other toxic elements; may contain plastics, glass, other non-organic materials;	Only small quantities available commercially at present, but some pilot projects underway; quantities could increase in future	Usually spread and incorporated	Little available information on longevity of effects
Humates	Not normally used for erosion control	No expected increase in soil organic matter at recommended application rates	Poor source of plant nutrients	Possible increase in soil aggregation and water holding capacity; possible decrease in hydraulic conductivity on sandy soils	Variable results on field trials; many of claims made by distributors not substantiated by research	Available from local suppliers; originally from sources in U.S.A.	Usually incorporated	Not recommende for use. Results are too variable
Mushroom Compost and Vermicompost	Not normally used for erosion control	Increase in soil organic matter with mushroom compost and vermicompost;	Good sources of some nutrients	Improvement in soil physical properties similar to municipal and yard compost	Materials are not normally available in quantity	Mushroom compost available from a number of mushroom producers throughout the province, but relatively small quantities are produced, and production is not likely to increase substantially in the near future. Vermicomposts not currently available commercially in the province	Usually incorporated	Good amendments where available

5. RECOMMENDATIONS FOR FURTHER STUDY

Although the literature on the use of various sources of organic matter as a soil amendment is extensive, there are a number of topics which have received insufficient attention to date, as follows:

1. Longevity of organic matter after addition. Work needs to be carried out on the longevity of effect of organic matter once it has been added to a soil, as a single application, as a series of applications over a period of time, and on the factors that affect its longevity. The relative longevity in the soil of different types of amendments needs to be assessed as well.
2. Effects of organic matter amendments on reclamation of small disturbances in Alberta. There is almost no well-documented information on the use of soil organic matter amendments on relatively small scale disturbances such as wellsites, sand and gravel pits, or pipelines. Organic amendments are commonly used to reclaim oil and gas wellsites for example, but research and properly documented case studies are almost non-existent.
3. Effects of organic matter amendments specific to reclamation in Alberta. There is a general lack of information on the effects of specific soil organic matter amendments which can be used for reclamation in Alberta. Adequate data on the chemical, physical and biological properties for Alberta organic amendments are not available. Much of the existing information is derived from the agricultural literature, and its direct relevance to land reclamation in Alberta needs into be assessed. Because of the agricultural bias of so much of the literature, there is very little information on the effects of amendments for the reclamation of sites to non-agricultural end-uses, for example forestry, or wildlife habitat.

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7. APPENDIX 1

Decomposition can be described by the mathematical expression of first order kinetics. This equation can be presented in several ways:

$$\text{(change in A)/(change in time)} = -kA \tag{eqn. 1}$$

$$At = Aoe^{-kt} \tag{eqn. 2}$$

$$\ln At - \ln Ao = -kt \tag{eqn. 3}$$

where: At is concentration of the substrate in the soil after time t
Ao is the original concentration of the substrate in the soil
t is time
k is the decomposition rate constant for the substrate under specified conditions

First order decomposition means that the rate of decomposition is dependent on the concentration of the substrate in soil. The decomposition rate is greater when more substrate is present. When most of the substrate has decayed and only a little is left, the overal rate of decay is much slower. The half-life (t-1/2) of a substrate is the amount of time it takes for half of the substrate to decay. The half life is related to the decomposition rate constant by the equation:

$$t\text{-}1/2 = 0.693/k \tag{eqn. 4}$$

Turnover times for materials that decay according to first-order kinetics can be described by:

$$mrt = -\ 1/k \tag{eqn. 5}$$

where: mrt is the mean residence time, also called turnover time of the substrate

A few qualifying statements should be made regarding the all of the above equations. First, it is important that the units be compatable. For example, if the rate constant k is expressed in units of year-1, then the time unit t has to be in units of years. Second, it is important to remember that the decay rate constant describes decomposition under specified conditions of temperature and moisture. It is necessary to use rate constants which are defined for the conditions of interest. If a rate constant was developed in the laboratory at room temperature and under ideal moisture conditions, then values will be totally unrepresentative if field conditions are very hot or cold, or very dry or wet. Third, sometimes it is practical to describe complex substates such as straw by splitting the substate into several components depending on decomposition rates. In other words, the decomposition of straw is sometimes described best by a three component equation, one for the rapidly decomposible material in straw, one for the medium decomposible material and another component for the very slowly decomposible material, such as lignin. This is described in more detail by McGill and Hoyt (1977), Paul and Clark (1989), and Juma and McGill (1986a,b). Fourth, the decay constant describes the decay of the original substate and does not account for the conversion of the substrates into new compounds by the microbial population. The decrease in soil carbon after an amendment addition occurs much slower than the actual disappearance of the amendment. Thus the disappearance of carbon from soil is not a good indication of the actual decay since microorganisms are incorporating some of this carbon into their bodies and by-products. The actual amount of substate decomposed can be calculated by the following equation from Paul and Clark (1989):

$$C = Ci(1 + Y/(100-Y)) \qquad \text{(eqn. 3)}$$

where: C is the substrate decomposed

Ci is the CO2 carbon evolved

Y is the percent efficiency of the use of carbon for biosynthesis

Fifth, if a soil receives an exceptionally heavy application of an amendment it may overload the soil such that the decomposition rate is not proportional to the amount of amendment applied. In this case the decomposition is said to follow zero order kinetics rather than the more common first order kinetics.

RECLAMATION RESEARCH REPORTS

1. **RRTAC 79-2: Proceedings: Workshop on Native Shrubs in Reclamation. P.F. Ziemkiewicz, C.A. Dermott and H.P. Sims (Editors). 104 pp. No longer available.**

The Workshop was organized as the first step in developing a Native Shrub reclamation research program. The Workshop provided a forum for the exchange of information and experiences on three topics: propagation; outplanting; and, species selection.

2. **RRTAC 80-1: Test Plot Establishment: Native Grasses for Reclamation. R.S. Sadasivaiah and J. Weijer. 19 pp. No longer available.**

The report details the species used at three test plots in Alberta's Eastern Slopes. Site preparation, experimental design, and planting method are also described.

3. **RRTAC 80-2: Alberta's Reclamation Research Program - 1979. Reclamation Research Technical Advisory Committee. 22 pp. No longer available.**

This report describes the expenditure of $1,190,006 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

4. **RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp. No longer available.**

This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

5. **RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi and H.F. Regier (Editors). 160 pp. $10.00**

Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

6. **RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. L.E. Watson, R.W. Parker and D.F. Polster. 2 vols, 541 pp. No longer available; replaced by RRTAC 89-4.**

Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their suitability for use in reclamation. Range maps, growth habit, propagation, tolerance, and availability information are provided.

7. **RRTAC 81-1: The Alberta Government's Reclamation Research Program - 1980. Reclamation Research Technical Advisory Committee. 25 pp. No longer available.**

This report describes the expenditure of $1,455,680 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

8. **RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp. $10.00**

This survey is an update of a report prepared in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

9. **RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stein, R. Leitch and G. Lutwick (Editors). 253 pp. $10.00**

Presents nine technical papers on the chemical, physical, and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites, and use of ash as a soil amendment. Workshop discussions and summaries are also included.

10. **RRTAC 82-1: Land Surface Reclamation: An International Bibliography. H.P. Sims and C.B. Powter. 2 vols, 292 pp. $10.00**

Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system (in a SPIRES database called RECLAIM). Vol. 2 comprises the keyword index and computer access manual.

11. **RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp. $5.00**

This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981, are available in the Alberta Environment Library.

12. **RRTAC 82-3: The Alberta Government's Reclamation Research Program - 1981. Reclamation Research Technical Advisory Committee. 22 pp. No longer available.**

This report describes the expenditure of $1,499,525 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

13. **RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp. No longer available**

Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of field trials (See RRTAC 92-4).

14. **RRTAC 83-2: The Alberta Government's Reclamation Research Program - 1982. Reclamation Research Technical Advisory Committee. 25 pp. No longer available.**

This report describes the expenditure of $1,536,142 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

15. **RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp. No longer available.**

Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop production.

16. **RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz (Editor). 123 pp. $10.00**

Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics, and resulting water quality. Mitigative measures and priorities were also discussed.

17. **RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Techman Engineering Ltd. 124 pp. No longer available.**

This is a review and analysis of information on planting stock quality, rearing techniques, site preparation, planting, and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

18. **RRTAC 84-1: Land Surface Reclamation: A Review of the International Literature. H.P. Sims, C.B. Powter and J.A. Campbell. 2 vols, 1549 pp. $20.00**

Nearly all topics of interest to reclamationists including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

19. **RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp. $10.00**

This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

20. **RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp. $5.00**

This report describes the expenditure of $1,529,483 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas and describes the projects funded under each program.

21. **RRTAC 84-4: Soil Microbiology in Land Reclamation. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser and J.C. Zak. 2 vols, 676 pp. $10.00**

This is a collection of five reports dealing with re-establishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

22. **RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz (Editor). 416 pp. No longer available.**

Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling, shrub propagation and establishment are presented.

23. **RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp. No longer available.**

This report describes the expenditure of $1,320,516 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas and describes the projects funded under each program.

24. **RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp. $10.00**

The report examines the critical issue of settling pond design, and sizing and alternative technologies. The study was co-funded with The Coal Association of Canada.

25. **RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp. No longer available.**

Reconstructed soils representing different materials handling and replacement techniques were characterized, and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

26. **RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp. $5.00**

In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

27. **RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp. $10.00**

This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establish a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

28. **RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 71 pp. $10.00**

This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

29. **RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp. $5.00**

The report deals with the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is in the Battle River Mining area in east-central Alberta.

30. **RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp. $5.00**

This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

31. **RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp. $5.00**

This report describes the expenditure of $1,168,436 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas and describes the projects funded under each program.

32. **RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp. No longer available.**

This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed. The study was co-funded with The Coal Association of Canada.

33. **RRTAC 87-1: Disposal of Drilling Wastes. L.A. Leskiw, E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford and H. Hamilton. 210 pp. No longer available.**

Current drilling waste disposal practices are reviewed and criteria in Alberta guidelines are assessed. The report also identifies research needs and indicates mitigation measures. A manual provides a decision-making flowchart to assist in selecting methods of environmentally safe waste disposal.

34. **RRTAC 87-2: Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. A.W. Fedkenheuer, L.J. Knapik and D.G. Walker. 174 pp. No longer available.**

This report reviews current reclamation practices with regard to site and soil reconstruction and re-establishment of biological productivity. It also identifies research needs in the Mountain-Foothills area. The study was co-funded with The Coal Association of Canada.

35. **RRTAC 87-3: Gel and Saline Drilling Wastes in Alberta: Workshop Proceedings. D.A. Lloyd (Compiler). 218 pp. No longer available.**

Technical papers were presented which describe: mud systems used and their purpose; industrial constraints; government regulations, procedures and concerns; environmental considerations in waste disposal; and toxic constituents of drilling wastes. Answers to a questionnaire distributed to participants are included in an appendix.

36. **RRTAC 87-4: Reclamation Research Annual Report - 1986. 50 pp. No longer available.**

This report describes the expenditure of $1,186,000 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas and describes the projects funded under each program.

37. **RRTAC 87-5: Review of the Scientific Basis of Water Quality Criteria for the East Slope Foothills of Alberta. Beak Associates Consulting Ltd. 46 pp. $10.00**

The report reviews existing Alberta guidelines to assess the quality of water drained from coal mine sites in the East Slope Foothills of Alberta. World literature was reviewed within the context of the East Slopes environment and current mining operations. The ability of coal mine operators to meet the various guidelines is discussed. The study was co-funded with The Coal Association of Canada.

38. **RRTAC 87-6: Assessing Design Flows and Sediment Discharge on the Eastern Slopes. Hydrocon Engineering (Continental) Ltd. and Monenco Consultants Ltd. 97 pp. $10.00**

The report provides an evaluation of current methodologies used to determine sediment yields due to rainfall events in well-defined areas. Models are available in Alberta to evaluate water and sediment discharge in a post-mining situation. SEDIMOT II (Sedimentology Disturbed Modelling Techniques) is a single storm model that was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining and is well suited to Alberta conditions. The study was co-funded with The Coal Association of Canada.

39. **RRTAC 87-7: The Use of Bottom Ash as an Amendment to Sodic Spoil. S. Fullerton. 83 pp. No longer available.**

The report details the use of bottom ash as an amendment to sodic coal mine spoil. Several rates and methods of application of bottom ash to sodic spoil were tested to determine which was the best at reducing the effects of excess sodium and promoting crop growth. Field trials were set up near the Vesta mine in East Central Alberta using ash readily available from a nearby coal-fired thermal generating station. The research indicated that bottom ash incorporated to a depth of 30 cm using a subsoiler provided the best results.

40. **RRTAC 87-8: Waste Dump Design for Erosion Control. R.G. Chopiuk and S.E. Thornton. 45 pp. $5.00**

This report describes a study to evaluate the potential influence of erosion from reclaimed waste dumps on downslope environments such as streams and rivers. Sites were selected from coal mines in Alberta's mountains and foothills, and included resloped dumps of different configurations and ages, and having different vegetation covers. The study concluded that the average annual amount of surface erosion is minimal. As expected, erosion was greatest on slopes which were newly regraded. Slopes with dense grass cover showed no signs of erosion. Generally, the amount of erosion decreased with time, as a result of initial loss of fine particles, the formation of a weathered surface, and increased vegetative cover.

41. **RRTAC 87-9: Hydrogeology and Groundwater Chemistry of the Battle River Mining Area. M.R. Trudell, R.L. Faught and S.R. Moran. 97 pp. No longer available.**

This report describes the premining geologic conditions in the Battle River coal mining area including the geology as well as the groundwater flow patterns, and the groundwater quality of a sequence of several water-bearing formations extending from the surface to a depth of about 100 metres.

42. **RRTAC 87-10: Soil Survey of the Plains Hydrology and Reclamation Project - Battle River Project Area. T.M. Macyk and A.H. MacLean. 62 pp. plus 8 maps. $10.00**

The report evaluates the capability of post-mining landscapes and assesses the changes in capability as a result of mining, in the Battle River mining area. Detailed soils information is provided in the report for lands adjacent to areas already mined as well as for lands that are destined to be mined. Characterization of the reconstructed soils in the reclaimed areas is also provided. Data were collected from 1979 to 1985. Eight maps supplement the report.

43. **RRTAC 87-11: Geology of the Highvale Study Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 78 pp. $10.00**

The report is one of a series that describes the geology, soils and groundwater conditions at the Highvale Coal Mine study site. The purpose of the study was to establish a summary of site geology to a level of detail necessary to provide a framework for studies of hydrogeology and reclamation.

44. **RRTAC 87-12: Premining Groundwater Conditions at the Highvale Site. M.R. Trudell and R. Faught. 83 pp. No longer available.**

This report presents a detailed discussion of the premining flow patterns, hydraulic properties, and isotopic and hydrochemical characteristics of five layers within the Paskapoo Geological Formation, the underlying sandstone beds of the Upper Horseshoe Canyon Formation, and the surficial glacial drift.

45. **RRTAC 87-13: An Agricultural Capability Rating System for Reconstructed Soils. T.M. Macyk. 27 pp. $5.00**

This report provides the rationale and a system for assessing the agricultural capability of reconstructed soils. Data on the properties of the soils used in this report are provided in RRTAC 86-2.

46. **RRTAC 88-1: A Proposed Evaluation System for Wildlife Habitat Reclamation in the Mountains and Foothills Biomes of Alberta: Proposed Methodology and Assessment Handbook. T.R. Eccles, R.E. Salter and J.E. Green. 101 pp. plus appendix. $10.00**

The report focuses on the development of guidelines and procedures for the assessment of reclaimed wildlife habitat in the Mountains and Foothills regions of Alberta. The technical section provides background documentation including a discussion of reclamation planning, a listing of reclamation habitats and associated key wildlife species, conditions required for development, recommended revegetation species, suitable reclamation techniques, a description of the recommended assessment techniques and a glossary of basic terminology. The assessment handbook section contains basic information necessary for evaluating wildlife habitat reclamation, including assessment scoresheets for 15 different reclamation habitats, standard methodologies for measuring habitat variables used as assessment criteria, and minimum requirements for certification. This handbook is intended as a field manual that could potentially be used by site operators and reclamation officers. The study was co-funded with The Coal Association of Canada.

47. **RRTAC 88-2: Plains Hydrology and Reclamation Project: Spoil Groundwater Chemistry and its Impacts on Surface Water. M.R. Trudell (Compiler). 135 pp. No longer available.**

Two reports comprise this volume. The first "Chemistry of Groundwater in Mine Spoil, Central Alberta," describes the chemical make-up of spoil groundwater at four mines in the Plains of Alberta. It explains the nature and magnitude of changes in groundwater chemistry following mining and reclamation. The second report, "Impacts of Surface Mining on Chemical Quality of Streams in the Battle River Mining Area," describes the chemical quality of water in streams in the Battle River mining area, and the potential impact of groundwater discharge from surface mines on these streams.

48. **RRTAC 88-3: Revegetation of Oil Sands Tailings: Growth Improvement of Silver-berry and Buffalo-berry by Inoculation with Mycorrhizal Fungi and N_2-Fixing Bacteria. S. Visser and R.M. Danielson. 98 pp. $10.00**

The report provides results of a study: (1) To determine the mycorrhizal affinities of various actinorrhizal shrubs in the Fort McMurray, Alberta region; (2) To establish a basis for justifying symbiont inoculation of buffalo-berry and silver-berry; (3) To develop a growing regime for the greenhouse production of mycorrhizal, nodulated silver-berry and buffalo-berry; and, (4) To conduct a field trial on reconstructed soil on the Syncrude Canada Limited oil sands site to critically evaluate the growth performance of inoculated silver-berry and buffalo-berry as compared with their un-inoculated counterparts.

49. **RRTAC 88-4: Plains Hydrology and Reclamation Project: Investigation of the Settlement Behaviour of Mine Backfill. D.R. Pauls (compiler). 135 pp. $10.00**

This three part volume covers the laboratory assessment of the potential for subsidence in reclaimed landscapes. The first report in this volume, "Simulation of Mine Spoil Subsidence by Consolidation Tests," covers laboratory simulations of the subsidence process particularly as it is influenced by resaturation of mine spoil. The second report, "Water Sensitivity of Smectitic Overburden: Plains Region of Alberta," describes a series of laboratory tests to determine the behaviour of overburden materials when brought into contact with water. The report entitled "Classification System for Transitional Materials: Plains Region of Alberta," describes a lithological classification system developed to address the characteristics of the smectite rich, clayey transition materials that make up the overburden in the Plains of Alberta.

50. RRTAC 88-5: Ectomycorrhizae of Jack Pine and Green Alder: Assessment of the Need for Inoculation, Development of Inoculation Techniques and Outplanting Trials on Oil Sand Tailings. R.M. Danielson and S. Visser. 177 pp. No longer available.

The overall objective of this research was to characterize the mycorrhizal status of Jack Pine and Green Alder which are prime candidates as reclamation species for oil sand tailings and to determine the potential benefits of mycorrhizae on plant performance. This entailed determining the symbiont status of container-grown nursery stock and the quantity and quality of inoculum in reconstructed soils, developing inoculation techniques and finally, performance testing in an actual reclamation setting.

51. RRTAC 88-6: Reclamation Research Annual Report - 1987. Reclamation Research Technical Advisory Committee. 67 pp. No longer available.

This annual report describes the expenditure of $500,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

52. RRTAC 88-7: Baseline Growth Performance Levels and Assessment Procedure for Commercial Tree Species in Alberta's Mountains and Foothills. W.R. Dempster and Associates Ltd. 66 pp. $5.00

Data on juvenile height development of lodgepole pine and white spruce from cut-over or burned sites in the Eastern Slopes of Alberta were used to define reasonable expectations of early growth performance as a basis for evaluating the success of reforestation following coal mining. Equations were developed predicting total seedling height and current annual height increment as a function of age and elevation. Procedures are described for applying the equations, with further adjustments for drainage class and aspect, to develop local growth performance against these expectations. The study was co-funded with The Coal Association of Canada.

53. RRTAC 88-8: Alberta Forest Service Watershed Management Field and Laboratory Methods. A.M.K. Nip and R.A. Hursey. 4 Sections, various pagings. $10.00

Disturbances such as coal mines in the Eastern Slopes of Alberta have the potential for affecting watershed quality during and following mining. The collection of hydrometric, water quality and hydrometeorologic information is a complex task. A variety of instruments and measurement methods are required to produce a record of hydrologic inputs and outputs for a watershed basin. There is a growing awareness and recognition that standardization of data acquisition methods is required to ensure data comparability, and to allow comparison of data analyses. The purpose of this manual is to assist those involved in the field of data acquisition by outlining methods, practices and instruments which are reliable and recognized by the International Organization for Standardization.

54. RRTAC 88-9: Computer Analysis of the Factors Influencing Groundwater Flow and Mass Transport in a System Disturbed by Strip Mining. F.W. Schwartz and A.S. Crowe. 78 pp. No longer available.

Work presented in this report demonstrates how a groundwater flow model can be used to study a variety of mining-related problems such as declining water levels in areas around the mine as a result of dewatering, and the development of high water tables in spoil once resaturation is complete. This report investigates the role of various hydrogeological parameters that influence the magnitude, timing, and extent of water level changes during and following mining at the regional scale. The modelling approach described here represents a major advance on existing work.

55. **RRTAC 88-10: Review of Literature Related to Clay Liners for Sump Disposal of Drilling Wastes. D.R. Pauls, S.R. Moran and T. Macyk. 61 pp. No longer available.**

The report reviews and analyses the effectiveness of geological containment of drilling waste in sumps. Of particular importance was the determination of changes in properties of clay materials as a result of contact with highly saline brines containing various organic chemicals.

56. **RRTAC 88-11: Highvale Soil Reconstruction Project: Five Year Summary. D.N. Graveland, T.A. Oddie, A.E. Osborne and L.A. Panek. 104 pp. $10.00**

This report provides details of a five year study to determine a suitable thickness of subsoil to replace over minespoil in the Highvale plains coal mine area to ensure return of agricultural capability. The study also examined the effect of slope and aspect on agricultural capability. This study was funded and managed with industry assistance.

57. **RRTAC 88-12: A Review of the International Literature on Mine Spoil Subsidence. J.D. Scott, G. Zinter, D.R. Pauls and M.B. Dusseault. 36 pp. $10.00**

The report reviews available engineering literature relative to subsidence of reclaimed mine spoil. The report covers methods for site investigation, field monitoring programs and lab programs, mechanisms of settlement, and remedial measures.

58. **RRTAC 89-1: Reclamation Research Annual Report - 1988. 74 pp. $5.00**

This annual report describes the expenditure of $280,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

59. **RRTAC 89-2: Proceedings of the Conference: Reclamation, A Global Perspective. D.G. Walker, C.B. Powter and M.W. Pole (Compilers). 2 Vols., 854 pp. No longer available.**

Over 250 delegates from all over the world attended this conference held in Calgary in August, 1989. The proceedings contains over 85 peer-reviewed papers under the following headings: A Global Perspective; Northern and High Altitude Reclamation; Fish & Wildlife and Rangeland Reclamation; Water; Herbaceous Revegetation; Woody Plant Revegetation and Succession; Industrial and Urban Sites; Problems and Solutions; Sodic and Saline Materials; Soils and Overburden; Acid Generating Materials; and, Mine Tailings.

60. **RRTAC 89-3: Efficiency of Activated Charcoal for Inactivation of Bromacil and Tebuthiuron Residues in Soil. M.P. Sharma. 38 pp. ISBN 0-7732-0878-X. $5.00**

Bromacil and Tebuthiuron were commonly used soil sterilants on well sites, battery sites and other industrial sites in Alberta where total vegetation control was desired. Activated charcoal was found to be effective in binding the sterilants in greenhouse trials. The influence of factors such as herbicide:charcoal concentration ratio, soil texture, organic matter content, soil moisture, and the time interval between charcoal incorporation and plant establishment were evaluated in the greenhouse.

61. **RRTAC 89-4: Manual of Plant Species Suitability for Reclamation in Alberta - 2nd Edition. Hardy BBT Limited. 436 pp. ISBN 0-7732-0882-8. $10.00.**

This is an updated version of RRTAC Report 80-5 which describes the characteristics of 43 grass, 14 forb and 34 shrub and tree species which make them suitable for reclamation in Alberta. The report has been updated in several important ways: a line drawing of each species has been added; the range maps for each species have been redrawn based on an ecosystem classification of the province; new information (to 1990) has been added, particularly in the sections on reclamation use; and the material has been reorganized to facilitate information retrieval. Of greatest interest is the performance chart that precedes each species and the combined performance charts for the grass, forb, and shrub/tree groups. These allow the reader to pick out at a glance species that may suit their particular needs. The report was produced with the assistance of a grant from the Recreation, Parks and Wildlife Foundation.

62. **RRTAC 89-5: Battle River Soil Reconstruction Project Five Year Summary. L.A. Leskiw. 188 pp. No longer available.**

This report summarizes the results of a five year study to investigate methods required to return capability to land surface mined for coal in the Battle River area of central Alberta. Studies were conducted on: the amounts of subsoil required, the potential of gypsum and bottom ash to amend adverse soil properties, and the effects of slope angle and aspect. Forage and cereal crop growth was evaluated, as were changes in soil chemistry, density and moisture holding characteristics.

63. **RRTAC 89-6: Detailed Sampling, Characterization and Greenhouse Pot Trials Relative to Drilling Wastes in Alberta. T.M. Macyk, F.I. Nikiforuk, S.A. Abboud and Z.W. Widtman. 228 pp. No longer available.**

This report summarizes a three-year study of the chemistry of freshwater gel, KCl, NaCl, DAP, and invert drilling wastes, both solids and liquids, from three regions in Alberta: Cold Lake, Eastern Slopes, and Peace River/Grande Prairie. A greenhouse study also examined the effects of adding various amounts of waste to soil on grass growth and soil chemistry. Methods for sampling drilling wastes are recommended.

64. **RRTAC 89-7: A User's Guide for the Prediction of Post-Mining Groundwater Chemistry from Overburden Characteristics. M.R. Trudell and D.C. Cheel. 55 pp. $5.00**

This report provides the detailed procedure and methodology that is required to produce a prediction of post-mining groundwater chemistry for plains coal mines, based on the soluble salt characteristics of overburden materials. The fundamental component of the prediction procedure is the geochemical model PHREEQE, developed by the U.S. Geological Survey, which is in the public domain and has been adapted for use on personal computers.

65. **RRTAC 90-1: Reclamation Research Annual Report - 1989. 62 pp. No longer available.**

This annual report describes the expenditure of $480,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

66. **RRTAC 90-2: Initial Selection for Salt Tolerance in Rocky Mountain Accessions of Slender Wheatgrass and Alpine Bluegrass. R. Hermesh, J. Woosaree, B.A. Darroch, S.N. Acharya and A. Smreciu. 40 pp. $5.00**

Selected lines of slender wheatgrass and alpine bluegrass collected from alpine and subalpine regions of Alberta as part of another native grass project were evaluated for their ability to emerge in a saline medium. Eleven slender wheatgrass and 72 alpine bluegrass lines had a higher percentage emergence than the Orbit Tall Wheatgrass control (a commonly available commercial grass). This means that as well as an ability to grow in high elevation areas, these lines may also be suitable for use in areas where saline soil conditions are present. Thus, their usefulness for reclamation has expanded.

67. **RRTAC 90-3: Natural Plant Invasion into Reclaimed Oil Sands Mine Sites. Hardy BBT Limited. 65 pp. $5.00**

Vegetation data from reclaimed sites on the Syncrude and Suncor oil sands mines have been summarized and related to site and factors and reclamation methods. Natural invasion into sites seeded to agronomic grasses and legumes was minimal even after 15 years. Invasion was slightly greater in sites seeded to native species, but was greatest on sites that were not seeded. Invasion was mostly from agronomic species and native forbs; native shrub and tree invasion was minimal.

68. **RRTAC 90-4: Physical and Hydrological Characteristics of Ponds in Reclaimed Upland Landscape Settings and their Impact on Agricultural Capability. S.R. Moran, T.M. Macyk, M.R. Trudell and M.E. Pigot, Alberta Research Council. 76 pp. $5.00**

The report details the results and conclusions from studying a pond in a reclaimed upland site in Vesta Mine. The pond formed as a result of two factors: (1) a berm which channelled meltwater into a series of subsidence depressions, forming a closed basin; and (2) low hydraulic conductivity in the lower subsoil and upper spoil as a result of compaction during placement and grading which did not allow for rapid drainage of ponded water. Ponds such as this in the reclaimed landscape can affect agricultural capability by: (1) reducing the amount of farmable land (however, the area covered by these ponds in this region is less than half of that found in unmined areas); and, (2) creating the conditions necessary for the progressive development of saline and potentially sodic soils in the area adjacent to the pond.

69. **RRTAC 90-5: Review of the Effects of Storage on Topsoil Quality. Thurber Consultants Ltd., Land Resources Network Ltd., and Norwest Soil Research Ltd. 116 pp. $10.00**

The international literature was reviewed to determine the potential effects of storage on topsoil quality. Conclusions from the review indicated that storage does not appear to have any severe and longterm effects on topsoil quality. Chemical changes may be rectified with the use of fertilizers or manure. Physical changes appear to be potentially less serious than changes in soil quality associated with the stripping and respreading operations. Soil biotic populations appear to revert to pre-disturbance levels of activity within acceptable timeframes. Broad, shallow storage piles that are seeded to acceptable grass and legume species are recommended; agrochemical use should be carefully controlled to ensure soil biota are not destroyed.

70. **RRTAC 90-6: Proceedings of the Industry/Government Three-Lift Soils Handling Workshop. Deloitte & Touche. 168 pp. $10.00**

This report documents the results of a two-day workshop on the issue of three-lift soils handling for pipelines. The workshop was organized and funded by RRTAC, the Canadian Petroleum Association and the Independent Petroleum Association of Canada. Day one focused on presentation of government and industry views on the criteria for three-lift, the rationale and field data in support of three- and two-lift procedures, and an examination of the various soil handling methods in use. During day two, five working groups discussed four issues: alternatives to three-lift; interim criteria and suggested revisions; research needs; definitions of terms. The results of the workshop are being used by a government/industry committee to revise soils handling criteria for pipelines.

71. **RRTAC 90-7: Reclamation of Disturbed Alpine Lands: A Literature Review. Hardy BBT Limited. 209 pp. $10.00**

This review covers current information from North American sources on measures needed to reclaim alpine disturbances. The review provides information on pertinent Acts and regulations with respect to development and environmental protection of alpine areas. It also discusses: alpine environmental conditions; current disturbances to alpine areas; reclamation planning; site and surface preparation; revegetation; and, fertilization. The report also provides a list of research and information needs for alpine reclamation in Alberta.

72. **RRTAC 90-8: Plains Hydrology and Reclamation Project: Summary Report. S.R. Moran, M.R. Trudell, T.M. Macyk and D.B. Cheel. 105 pp. $10.00**

This report summarizes a 10-year study on the interactions of groundwater, soils and geology as they affect successful reclamation of surface coal mines in the plains of Alberta. The report covers: Characterization of the Battle River and Wabamun study areas; Properties of reclaimed materials and landscapes; Impacts of mining and reclamation on post-mining land use; and, Implications for reclamation practice and regulation. This project has led to the publication of 18 RRTAC reports and 22 papers in conference proceedings and referred journals.

73. **RRTAC 90-9: Literature Review on the Disposal of Drilling Waste Solids. Monenco Consultants Limited. 83 pp. $5.00**

This report reviews the literature on, and government and industry experience with, burial of drilling waste solids in an Alberta context. The review covers current regulations in Alberta, other provinces, various states in the US and other countries. Definitions of various types of burial are provided, as well as brief summaries of other possible disposal methods. Environmental concerns with the various options are presented as well as limited information on costs and monitoring of burial sites. The main conclusion of the work is that burial is still a viable option for some waste types but that each site and waste type must be evaluated on its own merits.

74. **RRTAC 90-10: Potential Contamination of Shallow Aquifers by Surface Mining of Coal. M.R. Trudell, S.R. Moran and T.M. Macyk. 75 pp. $5.00**

This report presents the results of a field investigation of the movement of salinized groundwater from a mined and reclaimed coal mine near Forestburg into an adjacent unmined area. The movement is considered to be an unusual occurrence resulting from a combination of a hydraulic head that is higher in the mined area than in the adjacent coal aquifer, and the presence of a thin surficial sand aquifer adjacent to the mine. The high hydraulic head results from deep ponds in the reclaimed landscape that recharge the base of the spoil.

75. **RRTAC 91-1: Reclamation Research Annual Report - 1990. Reclamation Research Technical Advisory Committee. 69 pp. No longer available.**

This annual report describes the expenditure of $499 612 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program. The report lists the 70 research reports published under the program.

76. **RRTAC 91-2: Winter Soil Evaluation and Mapping for Regulated Pipelines. A.G. Twardy. 43 pp. ISBN 0-7732-0874-7. $5.00**

Where possible, summer soil evaluations are preferred for pipelines. However, when winter soil evaluations must be done, this report lays out the constraints and requirements for obtaining the best possible information. Specific recommendations include: restricting evaluations to the time of day with the best light conditions; use of core- or auger-equipped drill-trucks; increased frequency of site inspections and soil analyses; and, hiring a well-qualified pedologist. The province's soils are divided into four classes, based on their difficulty of evaluation in winter: slight (most soils); moderate; high; and, severe (salt-affected soils in the Brown and Dark Brown Soil Zones).

77. **RRTAC 91-3: A User Guide to Pit and Quarry Reclamation in Alberta. J.E. Green, T.D. Van Egmond, C. Wylie, I. Jones, L. Knapik and L.R. Paterson. 151 pp. ISBN 0-7732-0876-3. $10.00**

Sand and gravel pits or quarries are usually reclaimed to the original land use, especially if that was better quality agricultural or forested land. However, there are times when alternative land uses are possible. This report outlines some of the alternate land uses for reclaimed sand and gravel pits or quarries, including: agriculture, forestry, wildlife habitat, fish habitat, recreation, and residential and industrial use. The report provides a general introduction to the industry and to the reclamation process, and then outlines some of the factors to consider in selecting a land use and the methods for reclamation. The report is not a detailed guide to reclamation; it is intended to help an operator determine if a land use would be suitable and to guide him or her to other sources of information.

78. **RRTAC 91-4: Soil Physical Properties in Reclamation. M.A. Naeth, D.J. White, D.S. Chanasyk, T.M. Macyk, C.B. Powter and D.J. Thacker. 204 pp. ISBN 0-7732-0880-1. $10.00**

This report provides information from the literature and Alberta sources on a variety of soil physical properties that can be measured on reclaimed sites. Each property is explained, measurement methods, problems, level of accuracy and common soil values are presented, and methods of dealing with the property (prevention, alleviation) are discussed. The report also contains the results of a workshop held to discuss soil physical properties and the state-of-the-art in Alberta.

79. **RRTAC 92-1: Reclamation of Sterilant Affected Sites: A Review of the Issue in Alberta. M. Cotton and M.P. Sharma. 64 pp. ISBN 0-7732-0884-4. No longer available**

This report assesses the extent of sterilant use on oil and gas leases in Alberta, identifies some of the concerns related to reclamation of sterilant affected sites and the common methods for reclaiming these sites, and outlines the methods for sampling and analyzing soils from sterilant affected sites. The report also provides an outline of a research program to address issues raised by government and industry staff.

80. **RRTAC 92-2: Reclamation Research Annual Report - 1991. Reclamation Research Technical Advisory Committee. 55 pp. ISBN 0-7732-0888-7. No longer available.**

This report describes the expenditure of $485,065 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the five program areas, and describes the projects funded under each program. It also lists the 75 research reports that have been published to date.

81. **RRTAC 92-3: Proceedings of the Industry/Government Pipeline Reclamation Success Measurement Workshop. R.J. Mahnic and J.A. Toogood. 62 pp. ISBN 0-7732-0886-0. $5.00.**

This report presents the results of a workshop to identify the soil and vegetation parameters that should be used to assess reclamation success on pipelines in Alberta. Six soil parameters (topsoil admixing; topsoil replacement thickness; compaction; soil loss by erosion; texture; and salinity) and six vegetation parameters (plant density; species composition; ground cover; vigour; weeds/undesirable species; and rooting characteristics) were selected as most important. Working groups discussed these parameters and presented suggested methods for assessing them in the field.

82. **RRTAC 92-4: Oil Sands Soil Reconstruction Project Five Year Summary. HBT AGRA Limited. 109 pp. ISBN 0-7732-0875-5. $10.00**

This report documents a five year study of the effects of clay and peat amendments to oil sand tailings sand on survival and growth of trees and shrubs. Ten species (jack pine, white spruce, serviceberry, silverberry, buffaloberry, pin cherry, prickly/woods rose, Northwest poplar, green alder, and Bebb willow) were planted into tailings sand amended with three levels of peat and three levels of clay. The treatments were incorporated to a depth of 20 cm or 40 cm. Data are provided on plant survival and growth, root size and distribution, disease and small mammal damage, herbaceous cover, soil moisture, soil chemistry, and bulk density.

83. **RRTAC 92-5: A Computer Program to Simulate Groundwater Flow and Contaminant Transport in the Vicinity of Active and Reclaimed Strip Mines: A User's Guide. A.S. Crowe and F.W. Schwartz, SIMCO Groundwater Research Ltd. 104 pp. plus appendix. ISBN 0-7732-0877-1. NOTE: This report is only available from the Alberta Research Council, Publications Centre, 250 Karl Clark Road, P.O. Box 8330, Station F, EDMONTON, Alberta T6H 5R7 as ARC Information Series 119. The cost is $20.00 and the cheque must be made out to the Alberta Research Council.**

The manual describes a computer program that was developed to study the influence of coal strip mining on groundwater flow systems and to simulate the transport of generated contaminants, both spatially and in time, in the vicinity of a mine. All three phases of a strip mine can be simulated: the pre-mining regional groundwater flow system; the mining and reclamation phase; and, the post-mining water level readjustment phase. The model is sufficiently general to enable the user to specify virtually any type of geological conditions, mining scenario, and boundary conditions.

84. **RRTAC 92-6: Alberta Drilling Waste Sump Chemistry Study. Volume I: Report (Volume II: Appendices is only available through the Alberta Research Council, Publications Centre, 250 Karl Clark Road, P.O. Box 8330, Station F, EDMONTON, Alberta T6H 5R7. The cost is $15.00 and the cheque must be made out to the Alberta Research Council.). T.M. Macyk, S.A. Abboud and F.I. Nikiforuk, Alberta Research Council. 217 pp. ISBN 0-7732-0879-8. $10.00.**

This study synthesizes the data from sampling and analysis of the solids and liquids found in 128 drilling waste sumps across Alberta. Drilling waste types sampled included: 72 freshwater gel, 19 invert, 27 KCl, 2 NaCl, and 8 others. Data and statistics are tabulated by waste type, depth of the drill hole, and ERCB administrative region for both the solids and the liquids. Using preliminary loading limits developed by the government/industry Drilling Waste Review Committee, the report presents information on the volume and depth of waste that could be landspread, and the area required for landspreading. The oil and gas industry provided approximately $585,000 for the sampling and analysis phase of this study.

85. **RRTAC 93-1: Reclamation of Native Grasslands in Alberta: A Review of the Literature. D.S. Kerr, L.J. Morrison and K.E. Wilkinson, Environmental Management Associates. 205 pp. plus appendices. ISBN 0-7732-0881-X. $10.00.**

A review of the literature on native grassland reclamation was conducted to summarize the current state of knowledge on reclamation and restoration efforts within Alberta. The review is comprehensive, including an overview of the regulations and guidelines governing land use on native prairie; a description of the dominant grassland ecoregions in Alberta; a review of the common disturbance types, extent and biophysical effects of disturbance on native prairie within Alberta; a description of the factors which influence the degree of disturbance and reclamation; and examples of both natural and enhanced recovery of disturbed sites through the examination of selected case studies.

86. **RRTAC 93-2: Reclamation Research Annual Report - 1992. Reclamation Research Technical Advisory Committee. 56 pp. ISBN 0-7732-0883-6. $5.00.**

This report describes the expenditure of $474,705 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and the research strategies of the five programs, and describes the projects funded under each program. It also lists the 85 research reports that have been published to date.

87. **RRTAC 93-3: Catalogue of Technologies for Reducing the Environmental Impact of Fine Tailings from Oil Sand Processing. B.J. Fuhr, Alberta Research Council, D.E. Rose, Dereng Enterprises Ltd., and D. Taplin, Komex International Ltd. 63 pp. ISBN 0-7732-0885-2. $5.00.**

A catalogue containing 22 technologies for reducing the environmental impact of fine tailings derived from oil sands has been assembled. The report consists of an introduction to oil sand processing and fine tailings generation, a simple spreadsheet for comparing the technologies, and a process summary for each technology. The technologies were not evaluated for effectiveness. Rather, a detailed set of questions was prepared that highlights the environmentally-related information a proponent should have. These questions will help to form a basis for comparisons among the technologies.

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